This is an annotated copy of the GCMRC draft with Comments by David Braun, Sound Science LLC and GCDAMP Executive Coordinator, Science Advisors Program. The comments are intended to provide feedback to the GCMRC, Reclamation, and the TWG on ways in which the proposed work for FY18-20 might be clarified/improved/strengthened. The comments take the 2017 Knowledge Assessment findings (and recommendations) as one source of guidance, but more importantly focus on the implications of the LTEMP EIS/ROD objectives and specific needs highlighted by the EIS/ROD for "learning" through adaptive management. The comments below are intended for discussion purposes only and are not for citation, quotation, or wider distribution.

Preliminary Draft of the Grand Canyon Monitoring and Research Center's Triennial Work Plan and Budget for Fiscal Years 2018-2020

April 7, 2017

Project A. Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

1. Investigators

David J. Topping, Research Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
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2. Project Summary

The primary linkage between Glen Canyon Dam operations and the characteristics of the physical, biological, and cultural resources of the Colorado River ecosystem (CRe) downstream from Glen Canyon Dam is through the stage, discharge, water quality, and sediment transport of the Colorado River. This project makes and interprets the basic measurements of these parameters at locations throughout the CRe. The data collected by this project are used to implement the High Flow Experiment (HFE) Protocol (i.e., trigger and design HFE hydrographs), to evaluate the reach-scale sand mass-balance response to the HFE Protocol, and to evaluate the downstream effects of releases conducted under the Long-Term Experimental and Management Plan (LTEMP) EIS. The data collected by this project are also required by the other physical, ecological, and socio-cultural projects funded by the Glen Canyon Dam Adaptive Management Program (GCDAMP). Most of the project funds support basic data collection at USGS gaging stations, with only a small amount of project funds supporting interpretation of basic data. The funds requested under this proposal cover only ~70% of the costs required to operate and interpret data at the network of USGS gaging stations used by this project; other funding for this network is provided to the USGS Arizona Water Science Center from USGS headquarters, the Bureau of Land Management, and the Arizona Department of Environmental Quality.

This project is designed to provide measurements of stage (i.e., water elevation), discharge, water quality, and suspended sediment at sufficiently high temporal resolutions (~15-minute) to resolve changes in these parameters and to allow accurate determination of suspended-sediment loads for use in sediment budgeting. The proposed monitoring under this project will be very similar to that conducted over the last 5-10 years. The 3 elements of this project are as follows:

1. Stream gaging: This element partially funds the collection, interpretation, and serving of continuous 15-minute measurements of stage and discharge on the main-stem Colorado River at USGS streamflow gaging stations located at river miles (RM) 0,

Commented [DPB1]: I think it would be useful if each project statement explicitly states and explains how the project aligns with the monitoring and learning objectives embodied in the LTEMP EIS and ROD, as well as the long-term goals of the AMP overall. This presumably would go into a TWP overview chapter as well, where the projects are introduced in the context of the 'big picture' discussion of monitoring and research needs.

Commented [DPB2]: Some project statements formally designate their component actions as "Elements" while others do not. I found it helpful to have consistent identifiers for the components of each proposal ("Element" seems to work). Could that be done consistently for all projects?

Commented [DPB3]: Most projects focus on topics explicitly addressed in the 2017 Knowledge Assessment, in which expert teams sometimes identified significant gaps and weaknesses (unknowns and uncertainties) in existing knowledge. These unknowns or uncertainties variously stem from ambiguities or gaps in AMP/LTEMP resource management objectives, statistical limitations in existing data, gaps in present understanding of biological or ecological interactions, and so forth. Where appropriate, the descriptions of the proposed projects should identify and state how the work will address critical unknowns and uncertainties.

30, 61, 87, 166, and 225, and at gaging stations on the major tributaries and in a representative subset of the smaller, and formerly ungaged, tributaries.

2. Water quality: This element funds the collection, interpretation, and serving of continuous 15-minute measurements of water temperature, specific conductance (a measure of salinity), turbidity, and dissolved oxygen at the above-mentioned six main-stem Colorado River gaging stations, as well as continuous measurements of water temperature at additional stations on the Colorado River and in the major tributaries. In addition, this element partially funds the logistics required to make water-chemistry measurements (including measurements of nutrients) at gaging stations on the Colorado River.

Commented [DPB4]: Should refer reader to Project E.

3. Sediment transport and budgeting: This element funds the collection, interpretation, and serving of continuous 15-minute measurements and also episodic measurements of suspended sediment and bed sediment at the above-mentioned gaging stations on the Colorado River and its tributaries. The continuous suspended-sediment measurements at the six main-stem Colorado River gaging stations, and the episodic suspended-sediment measurements in the tributaries are used in the construction of mass-balance sand budgets. These budgets inform scientists and managers on the effects of dam operations on the sand mass balance in the CRe between Lees Ferry and Lake Mead (divided into six reaches). Increases in the sand mass balance in a reach indicate an increase in the amount of sand in that reach and therefore an increase in the amount of sand available for sandbar deposition during HFEs, whereas decreases in the sand mass balance in a reach indicate a net loss of sand from that reach.

All measurements made by this project are made using standard USGS and other peer-reviewed techniques. All of these measurements can be plotted and/or downloaded at: https://www.gcmrc.gov/discharge_qw_sediment/ or https://www.gcmrc.gov/discharge_qw_sediment/. Plots of continuous parameters can be made in time-series or duration-curve formats. In addition, the user-interactive mass-balance sand budgets for the six CRe reaches are available at this website.

In addition to the collection and serving of the basic streamflow, water-quality, and sediment-transport data, time is spent in this project interpreting the data and reporting on the results and interpretations in peer-reviewed articles in the areas of hydrology, water quality, and sediment transport. The interpretive papers published by this project are designed to address key questions relevant to river management, especially to management in the GCDAMP. During FY 2018-20, multiple journal articles and top-tier USGS reports will be published, including on the following topics:

- Analysis of Paria River hydrology 1920s-present with implications for long-term sediment management in the CRe (*lead author Topping*)
- Geomorphology, hydraulic geometry, and sediment transport in the Paria River (*lead author Topping*)
- Sediment transport and geomorphic change in the Little Colorado River, with implications for aquatic and riparian habitat in the lower Little Colorado River (*lead author Dean*)
- Initial evaluation of LTEMP flows on sediment storage in the CRe (*lead author Griffiths*)

Commented [DPB5]: Glad to see this. Many potential implications for long-term adaptive management. For example, does/will tamarisk defoliation in both watersheds affect sediment delivery patterns? How might changes in weather patterns affect watershed and flow-path erosion? Does land development in the huge, multi-state LCR watershed have the potential to affect sediment discharge (e.g., see https://legacy.azdeq.gov/environ/water/assessment/download/lg.pdf)?

In addition to these publications, additional data reports and interpretive reports will be published by project personnel and USGS cooperators.

3. Budget

FY 2018	
Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem	
Salaries	$473,491
Traveling and Training	$10,000
Operating Expenses	$90,000
Logistics	$106,146
Cooperators (non-USGS)	
USGS Cooperators	$540,098
USGS Burden	$176,706
Total	$1,396,441

FY 2018 Project Gross Totals: $ 1,396,441

FY 2019	
Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem	
Salaries	$487,696
Traveling and Training	$10,000
Operating Expenses	$90,000
Logistics	$108,269
Cooperators (non-USGS)	
USGS Cooperators	$547,500
USGS Burden	$180,951
Total	$1,424,416

FY 2019 Project Gross Totals: $ 1,424,416

FY 2020	
Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem	
Salaries	$502,327
Traveling and Training	$10,000
Operating Expenses	$90,000
Logistics	$110,434
Cooperators (non-USGS)	
USGS Cooperators	$555,050
USGS Burden	$185,318
Total	$1,453,129

FY 2020 Project Gross Totals: $ 1,453,129

Project B. Sandbar and Sediment Storage Monitoring and Research

1. Investigators

Paul E. Grams, Research Hydrologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Joseph E. Hazel, Jr., Research Associate, Northern Arizona University
Matt Kaplinski, Research Associate, Northern Arizona University
Keith Kohl, Surveyor, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Thomas M. Gushue, GIS Coordinator, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Ed Schenk, Physical Scientist, Grand Canyon National Park

2. Project Summary

Project Element 1. Monitoring sandbars using topographic surveys and remote cameras:

The purpose of this monitoring project is to provide annual status and long-term trends for sandbars and campsites in Glen, Marble and Grand Canyons. This information is used to evaluate the effects of dam operations, including high-flow experiments (HFE's), on sandbars and related resources. We propose to continue annual monitoring of the existing set of 45 long-term monitoring sites with annual surveys of sandbar area and volume and usable campsite area (subset of 37 sites). In addition, this project will include maintenance of remote cameras for daily monitoring at 42 sites and support for the Grand Canyon River Guides Adopt-a-Beach program, which provides an assessment of campsite condition from the perspective of river guides. The sandbar database and website for serving sandbar data and images will be maintained and improved. The methods for automated processing of remote camera images to calculate sandbar area that were developed during the FY15-17 triennial work plan will be implemented to provide monthly measurements of sandbar area for a subset of the monitoring sites. Work for this project will occur on one non-motorized river trip annually.

Project Element 2. Long-term Monitoring and Research on Sediment Storage and Physical Habitat Characteristics of the River Channel:

The purpose of this combined monitoring and research project is to provide assessment of long-term trends in sand storage and track changes in the spatial distribution of sand in the channel, eddies, and on exposed sandbars. This project will also include continued research on bedload sand transport, classification of bed composition, measurement of sand thickness, and flow modeling to support this and other projects.

We propose to make repeat maps of Lower Marble Canyon in 2018 and Eastern Grand Canyon in 2020. LMC was mapped previously in 2009 and 2012 and EGC was mapped in 2011 and 2014. Thus, the repeat maps made in this work plan will provide a record of

Commented [DPB6]: I understand that the lag time, before channel mapping results are available, means that before/after comparisons conditions for HFEs are not possible for some time after the HFE. Does this affect the usefulness of the mapping? Also, more generally, it might to have an explanation of how some of the mapping work aligns with the LTEMP EIS and ROD objectives as well as long-term AMP objectives.

changes for 9-year periods. In 2019, we propose to collect an initial map of Western Grand Canyon between Diamond Creek and Pearce Ferry. This segment, much of which was inundated by Lake Mead, is now an active river channel with gradient controlled by Pearce Ferry Rapid. This segment was a zone of sediment accumulation where the Colorado River formed a delta at high reservoir levels, but it is unknown whether sediment accumulation continues to occur or whether it is now a zone of net sediment evacuation. Much of the segment is lined with vertical cutbanks of eroding Lake Mead sediments. The information will be used to estimate cutbank erosion rates and evaluate options for managing sediment in the river channel. Work in the segment will be coordinated with the National Park Service, the Hualapai Tribe, and potential related work on San Juan and Colorado River deltas in Lake Powell. On each mapping trip, we will make measurements to estimate sand thickness where possible to develop improved estimates for the total (absolute) mass of sand storage in each river segment. We will also make measurements of bedload transport at each sediment gage to improve estimates for bedload sand transport.

We will use data collected in Marble Canyon between 2009 and 2016 to produce a series of two-dimensional (i.e., depth-averaged) flow models. These models will utilize bathymetry and near-channel topography collected during previous channel mapping trips, along with upland topography collected by the 2013 aerial overflight to predict flow depth, velocity, and inundation extent (modeled or "virtual" shorelines) from low flows (i.e. < 8,000 ft^3/s) to the historic flood of record (210,000 ft^3/s). Combined with a recently-developed two-dimensional flow model for Glen Canyon, this work will enable near-continuous predictions of inundation extents, fish/invertebrate habitat availability, and hydraulics in eddies throughout Marble Canyon, that will be used by numerous other projects in the triennial work plan. Work for this project requires one motorized river trip annually.

Commented [DPB7]: This may also be a zone of native fish species recruitment, and geospatial data are needed on macro- and meso-habitat structure to help fisheries teams understand how habitat conditions here may bear on expanding native fish populations in WGC and upward from there. Same concerns for non-native species as well.

Project Element 3. Sandbar Modeling:

The purpose of sandbar modeling is to improve capabilities for predicting sandbar response to dam operations, including HFE's. In the FY15-17 work plan progress was made on identifying patterns of sandbar response and developing a simple predictive model based on site characteristics, streamflow, and sediment supply. We propose to continue development and validation of that model in the first year of the FY18-20 triennial work plan. One of the challenges to the current modeling effort is that there is very little capacity for predicting sandbar response to HFEs of different magnitude, duration, or hydrograph shape. This is because most of the HFEs have had similar hydrographs, but with different sediment supply and antecedent sandbar conditions. This lack of controlled conditions in the field coupled with the expense of collecting detailed field measurements around each HFE makes it difficult to address questions about the effect of hydrograph characteristics on sandbar response based on field data alone. Therefore, we propose to investigate the effects of hydrograph shape on sandbar deposition and erosion with a set of laboratory flume experiments. Pilot experiments conducted in 2016 demonstrated the feasibility of conducting laboratory experiments on eddy sandbar formation in a large experimental channel.

Commented [DPB8]: Do any properties of the Paria sediment input affect these responses, too – not just mass but particle properties?

Project Element 4. Control Network and Survey Support:

This project element provides support to project elements 1 and 2 and to other projects that require repeatable geospatial measurements. The project requires one river trip in FY 2019 to complete control work between River Miles 87 and 166, in support of future remote sensing missions and mapping work.

3. Budget

FY 2018	
Project	
Salaries	$542,355
Traveling and Training	$5,900
Operating Expenses	$37,000
Logistics	$106,424
Cooperators (non-USGS)	$483,880
USGS Cooperators	
USGS Burden	$194,353
Total	$1,369,912

FY 2018 Project Gross Totals: $1,369,912

FY 2019	
Project	
Salaries	$558,626
Traveling and Training	$5,900
Operating Expenses	$22,000
Logistics	$141,534
Cooperators (non-USGS)	$483,880
USGS Cooperators	
USGS Burden	$203,812
Total	$1,415,752

FY 2019 Project Gross Totals: $1,415,752

FY 2020	
Project	
Salaries	$617,176
Traveling and Training	$5,900
Operating Expenses	$37,000
Logistics	$97,198
Cooperators (non-USGS)	$490,789
USGS Cooperators	
USGS Burden	$211,615
Total	$1,459,678

FY 2020 Project Gross Totals: $1,459,678

Project C. Riparian Vegetation Monitoring and Research

1. Investigators

Joel Sankey, Research Geologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Brad Butterfield, Northern Arizona University
Emily Palmquist, Ecologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Laura Durning, Northern Arizona University

2. Project Summary

Riparian vegetation affects physical processes and biological interactions along the channel downstream of Glen Canyon Dam. The presence and expansion of riparian vegetation promotes bank stability, diminishes the magnitude of scour and fill during floods, and has a role in wildlife habitat and recreational values. This project utilizes annual field measurements (**Element 1**) and digital imagery (**Element 2**) for integrated monitoring of changes in vegetation assessed at river segment and system-wide scales for vegetation associated with sandbars, debris fans and channel margins. Included in monitoring are: (1) a 5-year assessment of vegetation change (**Element 1**); (2) revisiting and updating the status of marsh area and composition as was done in 1995 by Stevens et al. (1995) (**Element 3**); and (3) analyzing a new system-wide remote sensing vegetation classification, providing a system-wide assessment of Tamarisk beetle defoliation from 2009-2013, and analyzing the sand/vegetation turnover dynamism (**Element 2**). Each part of the project elements provides an assessment of the status of plant communities identified as of interest or concern by stakeholders, and informs proposed research in support of the LTEMP and plant mitigation efforts.

Building on the modeling efforts of elements of the previous workplan, this project will also utilize existing data and new genetic data to examine the influence of dam operations on riparian vegetation distribution and composition in relation to limiting climatic factors (**Element 4**). The results of this work will inform the parameters in which vegetation management will be most successful and improve the State and Transition models for predicting vegetation response to changing dam operations. The vegetation monitoring and remote sensing products outlined above (and described below) will be integrated with flow-response vegetation guilds to develop predictive models of vegetation responses to LTEMP flow scenarios. These flow-response guilds categorize species by their predicted responses to variation in flow levels, which if accurate could greatly simplify and improve predicted responses to future flow scenarios. We will test these predictions based on responses observed in long-term monitoring data to a wealth of hydrological and geomorphological factors. These empirical relationships will be incorporated into a predictive model that generates probabilities of vegetation outcomes in response to specific future flow scenarios. These predicted outcomes will be generated across multiple spatial scales in order to better inform management.

Commented [DPB9]: It would be helpful if the project summary indicated how the proposed work addresses LTEMP EIS and ROD resource goals for Natural Processes, Riparian vegetation, and other resources. Also, the 2017 Knowledge Assessment responses from the Riparian Vegetation team indicated several areas of uncertainty about status and trends and external drivers. It would be useful if the project summary indicated explicitly how the proposed work will help redress these unknowns and uncertainties.

Commented [DPB10]: It also affects the mobility of exposed riverine sediment, which affects aeolian redistribution onto cultural sites.

Commented [DPB11]: I would say simply “affects”

Commented [DPB12]: The LTEMP ROD includes specific objectives for riparian vegetation conditions, but these are explicitly stated to be achieved through direct vegetation management. If direct management is the only management tool allowed, how important is it for the AMP to understand how flow and water table variation (in relation to geo-morphology) affect the details of vegetation? It seems more important to understand how topographic, sediment, and hydrologic conditions, including disturbance magnitude/frequency/timing, affect the suitability of different sites – and locations within these sites – as settings for establishing and managing specific suites of riparian vegetation.

Commented [DPB13]: Defoliation affects fire fuel loads. Should the monitoring include fire-risk assessments?

Commented [DPB14]: I assume this means improving the *prediction* of responses. Flow experiments are not carried out to manage riparian vegetation, so is there a need to ‘predict’ here, or just a need to understand how hydrologic conditions – including but not limited to flows – affect the vegetation. The ‘predictions’ in the latter view become means for testing the “how” model, to move from merely describing vegetation responses to the flow experiments, to understanding the “why” of these responses. That information, in turn, would be crucial for identifying the kinds of riparian vegetation that it should be possible to sustain in different locations and elevations and/or distances from river base-flow stage – i.e., information with which to guide restoration decision-making.

Commented [DPB15]: Since flows are not a tool for managing vegetation outcomes, the proposal needs to provide more information on how such modeling would help achieve LTEMP EIS/ROD and longer-term AMP goals. Part of the challenge here, though, is that the EIS/ROD and AMP goals may not be clear enough, at least in terms of what needs to be "learned" for adaptive management.

Lastly, causal relationships between dam operations and ecological outcomes can be difficult to infer from monitoring alone, yet manipulative experiments are understandably limited within the CRe. The NPS is interested in conducting vegetation plantings in order to expand desired vegetation states, but the long-term persistence of these and future plantings will depend on matching genetically suitable plant material to specific sites varying in substrate stability and existing vegetation. Vegetation plantings arranged in a "common garden" framework can be used to examine the success and utility of a variety of genotypes and species for vegetation management and identify reasonable constraints on movement of plant materials as they relate to conserving local genotypes. Plantings that are designed to contain multiple, replicated genotypes of species of interest can also be used for future research into the impacts of dam operations on community genetics (i.e., plant traits with a genetic foundation that influence the structure and function of the dependent ecosystem) and would permit assessment of patterns of local adaptation. In collaboration with the NPS, we will help to design vegetation plantings in such a way as to test predictions of models based on long-term observations, such as state and transition models, which will improve our ability to project the effects of alternative flow regimes on long-term stability of riparian vegetation and sandbar habitats (**Element 5**). Furthermore, as outlined in the LTEMP-ROD, the NPS, Tribes, and other stakeholders seek to preserve sand resources, camp sites, and archeological sites through vegetation removals. Through monitoring of post-removal vegetation trajectories, we can identify how successional processes interact with dam operations to reverse riparian vegetation expansion and determine the long-term preservation of camp sites, sand bars, sand dunes, and archaeological sites, as well as to prioritize needs for future interventions on a site-by-site basis. A final element of the project (**Element 6**) proposes to conduct decadal-scale vegetation monitoring based on replication of historical photographs and building on pilot work completed under the previous workplan.

Each of these project elements and associated objectives inform stakeholders about the status of vegetation and support analysis of vegetation's role in the ecological, physical, sociocultural responses to dam operations.

The elements and objectives for riparian vegetation and associated terrestrial resources are:

1. Ground-based riparian vegetation monitoring (Project Element 1; Brad Butterfield and Emily Palmquist).
    a. Annual measurement and analysis of plant cover and species presence to assess change as related to the geomorphic setting, elevation above the channel, and flow regime (FY18, 19, 20).
    b. Five-year summary of vegetation status and trends in relation to dam operations (FY19)
        i. Change in monitored parameters
        ii. Integration with other resources.

2. Imagery-based riparian vegetation monitoring at the landscape scale (Project Element 2: Joel Sankey and Laura Durning).
    a. Analysis and change detection of 2013 vegetation classification (FY18)

Commented [DPB16]: What are the "learning objectives" of this work? Shouldn't the identification of such objectives be the first priority? This would have to be a joint planning effort of the NPS, tribes, Reclamation, and the GCMRC. However, the entire stakeholder community should probably have a say as well, given that vegetation management is a matter of concern for recreational users, archaeological/cultural site managers, possibly fishery managers (shoreline vegetation effects on habitat, plant litter, etc.), and so forth. This is why the Science Advisors Program plan identifies a possible need for a 'riparian vegetation objectives' workshop, to clear up this larger question of learning objectives.

Commented [DPB17]: Are STMs really needed for this purpose, especially given that human manipulation will be the main driver of riparian succession and composition along the CRE. In my experience, STMs are not a typical modeling tool of choice for riparian communities other than to account for possible impacts of fire (e.g., see LANDFIRE and ESD programs), hence my asking about their applicability here.

Commented [DPB18]: Description should include information on the purpose of this element, relative to LTEMP EIS and ROD objectives and long-term AMP objectives.

   b. Vegetation and Sand Turnover/Dynamism 2002-2013 (FY18, 19)
   c. Tamarisk defoliation with overflight and satellite image analysis (NAU Thesis; FY 18)
   d. Integration of imagery land cover and other geospatial data for sand area and habitat (FY19)
   e. Overflight prep and operation 2020 – reevaluate specs? (FY20)

3. Revisit marsh community changes that were done in 1995 by Stevens et al. (Project Element 3; Joel Sankey, Brad Butterfield, Emily Palmquist, Laura Durning) (FY19, 20)
   a. Identify how marsh area changed since 1996/ROD. Has it increased, decreased, or remained stable?
   b. Has species composition in the marshes changed, and if so, in what ways?

4. Examine the relative influences of dam operations and environmental setting on riparian vegetation change. Use the resulting information to develop predictive models of vegetation responses to LTEMP flow scenarios. (Project Element 4; Brad Butterfield and Emily Palmquist) (FY 18, 19, 20)
   a. Use existing data and new genetic data in a Hierarchical Bayesian modeling framework to examine the influence of dam operations on riparian vegetation distribution and composition in relation to limiting climatic factors.
   b. Integrate the flow-response models with data and products from work outlined above to develop predictive models of vegetation responses to LTEMP flow scenarios.

Commented [DPB19]: Purpose not clear w/r/t objectives in EIS and ROD.

5. Vegetation management monitoring and research (Project Element 5; Joel Sankey, Brad Butterfield, Emily Palmquist, Laura Durning) (FY 18, 19, 20)
   a. Assist in the design of vegetation plantings, such that vegetation management goals and future research goals can be met.
   b. Assist NPS & Tribes with the monitoring design and data analysis associated with vegetation removal for sand dunes and archeological site preservation (See Project D).

Commented [DPB20]: Crucial to begin with learning objectives for this experimentation – see my earlier comment above.

6. Decadal-scale vegetation monitoring based on replication of historical photographs (Project Element 6; Helen Fairley)
   a. Replicate historical photographs that have not been previously or recently duplicated (e.g. photographs by Goldwater (1940), Kolb (1923), Weeden (1978) to provide a baseline visual record of riparian vegetation conditions at the start of the LTEMP period, and a basis for comparison of changes 20 years from now.

Commented [DPB21]: With all the aerial monitoring going on, shouldn't the purpose of the ground-level photography be (or include) to improve the usefulness of the remote sensing via ground-truthing? Also, given the logistical costs and safety risks for retaking ground-level photos, couldn't this be something done via drones with GPS control, or aided by incorporating participation by other field efforts, to take advantage of having others out there already (e.g., tribal monitors)?

3. Budget

FY 2018	
Project	
Salaries	$282,572
Traveling and Training	$41,085
Operating Expenses	$19,000
Logistics	$73,500
Cooperators (non-USGS)	$218,000
USGS Cooperators	$0
USGS Burden	$114,741
Total	$748,898

FY 2018 Project Gross Totals: $748,898

FY 2019	
Project	
Salaries	$291,049
Traveling and Training	$38,410
Operating Expenses	$15,500
Logistics	$78,700
Cooperators (non-USGS)	$224,000
USGS Cooperators	$0
USGS Burden	$116,871
Total	$764,530

FY 2019 Project Gross Totals: $764,530

FY 2020	
Project	
Salaries	$299,780
Traveling and Training	$38,410
Operating Expenses	$18,000
Logistics	$80,900
Cooperators (non-USGS)	$230,000
USGS Cooperators	$0
USGS Burden	$120,544
Total	$787,634

FY 2020 Project Gross Totals: $787,634

Project D. Effects of vegetation management and dam operations for geomorphic condition and sand resources at archaeological sites and source-bordering dunefields

1. Investigators

Joel Sankey, Research Geologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Helen Fairley, Social Scientist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Amy East, Research Geologist, U.S. Geological Survey, Pacific Coastal and Marine Science Center

2. Project Summary

This project provides scientific information on the geomorphic effects of vegetation management and dam operations which will be undertaken per the LTEMP ROD during the next 20 years. These data and analyses will allow the GCDAMP to objectively evaluate whether and how those non-flow and flow actions affect the geomorphic condition and sand resources of archaeological sites and source-bordering dunefields located in the river corridor downstream of Glen Canyon Dam. This project is cognizant that the National Park Service at Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GLCA) and Native American tribes have programs to monitor cultural resource sites and related resources of interest, and it has been developed with the intent to complement, not duplicate, those other monitoring efforts.

Commented [DPB22]: This overlaps with Project C, Element 5b. Text should be specific about how Projects C and D complement. Project D appears to be mostly about the second half of its title: "geomorphic conditions and sand resources at archaeological sites and source-bordering dunefields."

The objectives for this project are to:

1. Use baseline data to monitor the physical condition of archaeological sites, associated dunefields, and their sand supply as a function of (i) vegetation management conducted by NPS and tribes per the LTEMP ROD, and (ii) dam operations, via:
    a. Site-specific topographic surveys (e.g., lidar, structure-from-motion, total station) and subsequent geomorphic change detection
    b. Morphological sediment budgeting to quantify the role of individual processes (e.g.., fluvial, aeolian, hillslope sediment transport) in driving geomorphic change at sites
    c. Sediment tracer experiments to quantify the degree of sediment connectivity between sandbars and dunefields at individual sites over annual timescales
    d. Analysis of archaeological site classification data acquired for all river-corridor sites to assess future erosion vulnerability and make inferences

about the role of dam operations in driving geomorphic change at sites and associated source-bordering dunefields

Note that work completed during this and previous workplans related to this objective and Objectives 3 and 4 (below) will be useful in collaborations with the NPS and tribes to identify sites and design vegetation removal treatments.

2. Determine rates and future susceptibility of terraces to erosion from dam operations (e.g., discharge) in GLCA. This will involve collaboration with GLCA archaeology staff and include an update of the assessment of dam-related geomorphic changes in Glen Canyon published by Grams et al. (2007; "*The rate and pattern of bed incision and bank adjustment on the Colorado River in Glen Canyon downstream from Glen Canyon Dam, 1956–2000*"; http://bulletin.geoscienceworld.org/content/119/5-6/556) with post-2000 imagery, topography, bathymetry, and flow (inundation) modelling, as well as additional terrace and vegetation mapping. This will result in an evaluation of contemporary (post-2000) changes to Glen Canyon terraces, shorelines, and riparian vegetation that are vital for preserving cultural resources and archaeological sites.
3. Implement the new software utility published by Kasprak et al. (2017), which determines site-scale sediment budgets and the relative contributions of individual sediment transport processes (e.g., fluvial, aeolian, hillslope transport) in driving geomorphic changes, to evaluate contemporary erosion rates of terraces and other pre-dam river sediment deposits as a function of dam operations on a reach-scale basis in Glen, Marble and Grand Canyons. This will include developing a web-mapping framework, hosted by GCMRC, to allow public use of the software utility.
4. Synthesize ongoing and historic data from this and the sandbar and channel mapping project (i.e., of Grams; "*Sandbar and Sediment Storage Monitoring and Research*") to quantify the influence of Glen Canyon Dam discharge and ongoing vegetation encroachment on altering the areal extent of bare sand available for fluvial and aeolian transport from Glen Canyon Dam to Diamond Creek (this work was completed in FY17 by Kasprak for the Lower Marble Canyon reach and is now proposed to be extended throughout Grand Canyon). The results of this work can be used to identify appropriate areas for targeted vegetation removal and to identify and assess vulnerability of sites and specific reaches to future geomorphic changes.

Commented [DPB23]: This is the overlap with Project C. Text needs to make clear how C and D are complementary.

Commented [DPB24]: Wouldn't bed incision and bank adjustment potentially also affect gullying radiating upward from channel, affecting fluvial terraces and higher settings?

Commented [DPB25]: Affected not only by dam operations but also by channel sediment dynamics, local weather (e.g., precipitation), vegetation, etc.

Commented [DPB26]: Is this meant as a statement about a theoretical possibility, or meant as an explicit objectives, to make the results usable in this manner? And if the latter, how will this application be implemented?

3. Budget

FY 2018	
Project	
Salaries	$311,126
Traveling and Training	$22,500
Operating Expenses	$30,000
Logistics	$34,000
Cooperators (non-USGS)	$0
USGS Cooperators	$30,000
USGS Burden	$103,383
Total	$531,009

FY 2018 Project Gross Totals: $531,009

FY 2019	
Project	
Salaries	$314,322
Traveling and Training	$22,500
Operating Expenses	$24,000
Logistics	$37,000
Cooperators (non-USGS)	$58,000
USGS Cooperators	$31,000
USGS Burden	$105,174
Total	$591,996

FY 2019 Project Gross Totals: $591,996

FY 2020	
Project	
Salaries	$317,430
Traveling and Training	$22,500
Operating Expenses	$27,000
Logistics	$39,000
Cooperators (non-USGS)	$0
USGS Cooperators	$32,000
USGS Burden	$105,542
Total	$543,472

FY 2020 Project Gross Totals: $543,472

Project E. Nutrients and temperature as ecosystem drivers: Understanding patterns, establishing links and developing predictive tools for an uncertain future

1. Investigators

Charles B. Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Bridget R. Deemer, Research Ecologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Kimberly Dibble, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Theodore Kennedy, Research Ecologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Michael Yard, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
David Ward, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

2. Project Summary

Changes in Lake Powell reservoir elevations have affected water temperatures in the Colorado River ecosystem (CRe) in the past. Specifically, years with lower reservoir elevations have been associated with warmer water temperatures (i.e., maximum release temperature of 13-16 °C), while years with higher reservoir elevations have led to cooler releases (i.e., maximum release temperatures of 11-12 °C). Past work has emphasized the positive impacts of this modest warming on native fish. Based on other systems, we would expect this warming to have neutral to positive effects on rainbow trout (well fed rainbow trout should have a temperature preference around 16 °C). However, recent bioenergetics modelling and fisheries data indicate that if food base availability does not keep pace with warming water temperatures, the outcomes are actually negative for both rainbow trout and native fish. For example, in 2011, water temperatures were warmer than average and both rainbow trout and humpback chub had high survival and growth. In contrast, 2014 had similar water temperatures to 2011, but rainbow trout had low survival and growth, humpback chub adults became skinnier (i.e., fish condition declined), and the humpback chub juvenile population declined substantially. Data presented at the January 2017 annual reporting meeting indicate inter-annual variation in the phosphorus concentrations of water released from Lake Powell may explain the different fish response in these two years.

Nutrients like nitrogen and phosphorus serve as the building blocks for all life, and their form and relative availability can exert an important control on biological communities and on key ecosystem processes. Phosphorous (specifically soluble reactive phosphorous - SRP) is required by primary producers (i.e., algae) and levels in the water

Commented [DPB27]: Is there a need to coordinate monitoring below the dam with monitoring in Lake Powell, e.g., specifically to record data on system state immediately prior to experimental releases? And if so, would that be better coordinated by including someone from Reclamation and GLCA on the investigative team?

Commented [DPB28]: Could note that the nutrient and temperature work falls under the LTEMP EIS and ROD resource goals for Natural Processes, HBC, RBT, Other Native Fish, and Nonnative Invasive Species. Also, the 2017 Knowledge Assessment responses from the Aquatic Food Base and Water Quality teams indicated several areas of uncertainty about status and trends and external drivers. It would be useful if the project summary indicated how the proposed work will help redress these unknowns and uncertainties, anywhere where it does not already do so.

Commented [DPB29]: Based on recent presentations, it looks like lake temperature distribution is affected not just by elevation but by internal dynamics affecting vertical structure and movement of inflow pulses both horizontally and vertically from lake inflows to forebay. So antecedent conditions affecting lake discharge temperature are multi-variate. Wouldn't it help to document all of the potentially relevant variables of antecedent lake system state?

Commented [DPB30]: I think this is one of the important breakthroughs of recent years, not only in recognizing key drivers, but in opening the door to a recognition of the way(s) in which the antecedent state of Lake Powell can affect the state of the CRE, and the time scales over which these dynamics play out.

released by Lake Powell are always quite low, making it a likely candidate to be a limiting resource. Furthermore, SRP concentrations have varied substantially over time. For example, SRP was 3-4x higher in 2011 than in 2014. Preliminary data suggest that declines in SRP availability in 2014 propagated through the entire food web, constraining rates of primary production, invertebrate production, and ultimately suppressing the recruitment of rainbow trout at Lees Ferry and the condition of adult humpback chub near the Little Colorado River (LCR) confluence. These results suggest that SRP concentrations in the water released from Lake Powell can be a bottom-up control at least 120 river kilometers below Glen Canyon Dam. However, it is unclear if these effects carry further downriver.

As we travel downriver, the potential impacts of nutrients and water temperature may change. With respect to temperature, even in 'warm' years like 2005, temperatures near the LCR confluence are too low to allow for mainstem reproduction by native fish, so temperature mainly affects fish growth and condition. Farther downriver, 'warm' years may actually provide temperatures that allow for mainstem reproduction of humpback chub - this is significant given that mainstem reproduction or a second spawning population would be an important step towards recovery. Thus, predicting responses of downriver native fish populations to management alternatives in the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) was mainly accomplished through comparing temperature model output to humpback chub temperature requirements for reproduction. Although the Wright et al. (2008) temperature model has been a valuable tool for fish and EIS modeling efforts, recent analyses by K. Dibble (USGS, unpublished data) indicate it has systematically underestimated summer temperatures in the most western parts of Grand Canyon by approximately 2 °C over the last decade. Thus, there is a need to revisit this model, especially since higher than forecasted temperatures in western Grand Canyon may facilitate warmwater species invasion from Lake Mead.

With respect to nutrients, we have a very poor understanding of how nutrient concentrations change longitudinally through the river in response to in-river ecosystem processes, interactions with riparian zones, and tributary inputs. The results presented at the annual reporting meeting were all based on SRP concentrations at penstock depth in Lake Powell, two miles from the Dam. While there are some measurements in Lees Ferry, they have been collected haphazardly with respect to time of day (uptake by primary producers depresses SRP levels during the middle of the day), and to our knowledge there are no measurements of SRP downstream of the Paria River. In other words, while tributaries like the Paria River and the LCR are the major drivers of sediment and organic matter budgets in the Colorado, their role in nutrient budgets is unknown. If nutrients remain low in western parts of the CRe, the resulting low food availability could counteract the expected benefits of increased temperature via bioenergetics constraints on growth and reproduction of native fish.

The important role of nutrients has been overlooked in the past, in part, because variation in SRP has frequently coincided with unusual dam releases (e.g., over the past 16 years, SRP was highest in 2011 and 2012 corresponding to 2011 equalization flows), potentially leading to an overemphasis of flow impacts in the models used to predict fish population responses and compare alternate management strategies as part of LTEMP EIS. More broadly, the fish population models used to make predictions for the LTEMP

Commented [DPB31]: Have detection limits been consistent? Also, given the likely intense recycling of P within the food web, even low SRP values could correspond to significant impacts, since SRP would represent only the proverbial "tip of the iceberg" in terms of P within the ecosystem.

Commented [DPB32]: Good point, clearly relevant to adaptive management objectives. A side question: do water temperatures vary with time of day and depth, and might this vertical and temporal variation affect fish biology?

Commented [DPB33]: Also, you probably have only limited information about N and especially P in biomass versus in the water. Given that system may be P-limited, wouldn't most P be in biomass rather than in the water (and in substrates?).

Commented [DPB34]: Does the lake SRP lose solubility after emerging into the more oxidative CRE environment?

Commented [DPB35]: Need to distinguish between biological availability versus presence in biomass and substrates? Low concentrations in water also raise questions about detection threshold requirements.

EIS, while a step in the right direction, were still fairly narrow in their treatment of drivers and representation of ecosystem processes. In other words, the models linking directly from flow and temperature predictors to fish populations become increasingly tenuous when making extrapolations to a highly uncertain future.

Physical and biogeochemical processes in Lake Powell (e.g., wind regime and associated mixing, degree of exposure of deltaic sediments, reservoir elevation, biological uptake, presence of quagga mussels, dissolved oxygen concentrations, and the magnitude, temperature, and nutrient makeup of inflows to the reservoir) are likely to play an important role in determining the nutrient concentration of dam releases. Still, we currently lack a good quantitative understanding of the reservoir processes that determine variation in nutrient concentrations in Lake Powell's outflow. Dynamic changes to the CRe over the next years to decades necessitate the development of models that can better characterize the most important controls on nutrients. For example, increases in quagga mussels in Lake Powell will likely lead to declines in phytoplankton concentrations of releases, but could actually increase concentrations of dissolved nutrients in releases. This, in turn, could increase primary production in the CRe and favor invertebrates dependent on in-stream primary production. In contrast, this pattern could be reversed over the coming years if declining storage in Lake Powell due to drought leads to released water being drawn from warmer, nutrient poor surface waters closer to the surface of the reservoir. A quantitative model of Lake Powell nutrient dynamics could also improve the ability to appropriately trigger certain flow management strategies (e.g., trout management flows), and interpret the effects of other flow management strategies (e.g., various configurations of high flow experiments and macroinvertebrate production flows).

To address these critical management uncertainties, we propose a multi-pronged approach that aims to advance learning about spatial and temporal patterns of nutrients and temperature, establish links between these drivers and Colorado River food webs, and develop predictive tools to aid future management decisions. Specifically, we propose: 1) the development of a model to predict nutrient concentrations in Lake Powell, which will be supported by analysis of historic data and targeted sampling within Lake Powell to fill knowledge gaps, 2) improved monitoring of nutrients in Lees Ferry, and longitudinal studies of nutrients throughout the Colorado River to understand patterns and drivers and develop a nutrient budget, 3) development of an improved temperature model for the CRe based on exponential warming (as opposed to the current linear form) using a longer-time series of data, 4) monitoring, modelling and research on the patterns and drivers of ecosystem metabolism (including primary production and respiration) throughout the Colorado River, 5) surveys of aquatic vegetation composition and biomass in Lees Ferry with the goal of establishing a cost-effective monitoring scheme, 6) artificial stream experiments at the Lees Ferry boat ramp or Glen Canyon Dam using Colorado River water to determine how primary producers and invertebrates respond to variation in temperatures, nutrient availability, and nutrient ratios (N:P) within current ranges of variation and under scenarios based on potential future conditions, and 7) aquatic ecosystem models to better link our understanding of various drivers of ecosystem change.

Commented [DPB36]: Plus the lag effects that result from the ways in which inflow pulses move through and affect lake geochemical structure…

Commented [DPB37]: Excellent connecting of proposed studies to EIS/ROD and long-term AMP objectives. However, need modeling that efficiently produces these kinds of forecasts for AMP, without excessive cost. Would off-the-shelf software such as CE-QUAL-W2 be good enough? Is there an existing Lake Powell model that could simply be updated to generate the needed forecasts with acceptable accuracy?

Commented [DPB38]: The knowledge assessment spreadsheet for the aquatic food base mentions allochthonous inputs as possible component of riverine nutrient budget. Is riparian litter only mobilized substantially during HFEs, or do rainstorm runoff and wind transport also carry terrestrial organic matter into the river? In a nutrient-starved system such as the CRE, wouldn't even modest inputs of litter matter? Is it worthwhile to explore the possible role of allochthonous inputs to the C/N/P budget in the river?

Commented [DPB39]: Do you need or have a way to assess primary production, including suspended, substrate, and macrophyte components? Also, given that most P is stored in invertebrate and vertebrate tissue, is there a way to estimate total P storage in the system, so you can assess how much the lake inputs may affect total ecosystem P and its effects on total biomass? (I also wonder if mechanical removal of fish biomass – by anglers as well as by fishery managers – could result in the export of an ecologically significant fraction of total ecosystem P).

References
Wright, S. A., C. R. Anderson, and N. Voichick. 2008. A simplified water temperature model for the Colorado River below Glen Canyon Dam. River Research and Applications **25**:675-686.

3. Budget

FY 2018	
Project	
Salaries	$357,582
Traveling and Training	$16,920
Operating Expenses	$157,754
Logistics	$14,700
Cooperators (non-USGS)	$0
USGS Cooperators	$0
USGS Burden	$142,209
Total	$689,164

FY 2018 Project Gross Totals: $ 689,164

FY 2019	
Project	
Salaries	$310,673
Traveling and Training	$13,100
Operating Expenses	$100,900
Logistics	$12,700
Cooperators (non-USGS)	$0
USGS Cooperators	$0
USGS Burden	$113,717
Total	$551,090

FY 2019 Project Gross Totals: $ 551,090

FY 2020	
Project	
Salaries	$294,043
Traveling and Training	$13,000
Operating Expenses	$88,497
Logistics	$12,700
Cooperators (non-USGS)	$0
USGS Cooperators	$0
USGS Burden	$106,142
Total	$514,381

FY 2020 Project Gross Totals: $ 514,381

Project F. Aquatic Invertebrate Ecology (food base)

1. Investigators

Theodore Kennedy, Research Ecologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Mike Dodrill, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Kim Dibble, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Charles Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Mike Yard, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
David Lytle, Professor, Department of Integrative Biology, Oregon State University

2. Project Summary

The GCMRC aquatic ecology (food base) group will conduct studies in four broad themes for the FY 2018–2020 Triennial Workplan. This work consists of continuing existing food base monitoring, initiating new monitoring to better understand underlying causes of recent apparent humpback chub, brown trout, and quagga mussel range expansions, characterizing food base responses to novel experimental flow releases from Glen Canyon Dam (GCD), and exploring links between flow management and food base conditions across many dams to better understand the role that operations of Glen Canyon Dam may be playing in determining the health of the food base in the Colorado River.

Commented [DPB40]: Could note that the food base work falls under the LTEMP EIS and ROD resource goals for Natural Processes, HBC, RBT, Other Native Fish, and Nonnative Invasive Species. Also, as noted vis Project E, the 2017 Knowledge Assessment responses from the Aquatic Food Base team indicated several areas of uncertainty about status and trends and external drivers. It would be useful if the project summary here indicated how the proposed work will help redress these unknowns and uncertainties, anywhere where it has not already done so (thanks for that).

1. *Continuation of existing food base monitoring programs*

Commented [DPB41]: Aquatic insects aren't actually the 'base' of the food web, but the first tier of consumers. What do we know about feeding guilds for the aquatic insects and about the organic matter on which they feed?

A primary focus of the food base group in this work plan is continuation of existing long-term monitoring. Specifically, we will continue monitoring invertebrate drift in Glen and Marble Canyons, which now represent datasets spanning 10 and 6 years, respectively. We will also continue the citizen science light trapping project that monitors adult aquatic insect populations throughout Marble and Grand Canyons, now in its sixth year. We will continue the similar sticky and pitfall trap monitoring of emergent adult aquatic insects and terrestrial insects in Glen Canyon, now in their fourth and second years, respectively, to describe invertebrate distribution patterns and long-term trends in the Lees Ferry reach of the Colorado River ecosystem. All of these long-term monitoring data provide baseline information on the status of the food base resource and will continue at a level of effort similar to prior years.

2. *Monitoring in support of humpback chub and invasive species range expansions*

In response to new of native humpback chub and expansion of invasive brown trout and quagga mussels, we will conduct new research and monitoring

Commented [DPB42]: New aggregations? Or new data on aggregations and the expansions?

to determine whether the aquatic food base is influencing the dynamics and range expansions of these populations. In conjunction with humpback chub studies, we will quantify invertebrate drift and fish feeding habits as part of the "JCM West" fisheries work in western Grand Canyon (see Project G), which would mirror similar efforts around the LCR confluence from 2012-2016. We will also conduct drift and emergence research in the Colorado River reach downstream of Diamond Creek, where very little is known about the condition of the aquatic food base, and where humpback chub and razorback sucker populations are growing and expanding. As part of these expanded food base monitoring efforts, we will quantify the energy content of invertebrate prey using lipid class analysis and comparing fatty acid profiles of invertebrate prey with fish tissues to make inferences about the contribution of specific prey items to fish growth. Lipids and fatty acids are a key component of many fish tissues including gametes. Thus, monitoring the lipid content and fatty acid profiles of invertebrate prey and fishes among sites will aid interpretation of humpback chub growth and reproductive potential among sites, particularly at downstream locations where there is evidence of recent spawning.

We will also continue aquatic food base monitoring in tributaries where humpback chub occur. Specifically, we will collaborate with the U.S. Fish and Wildlife Service to monitor the aquatic food base in the Little Colorado River during the spring and fall humpback chub monitoring trips. In collaboration with National Park Service, we will also initiate new food web research in Bright Angel Creek, Havasu Creek, and Shinumo Creek, locations where humpback chub have been translocated or are proposed for translocation once conditions such as food base availability are suitable. Research in downstream tributaries will be similar to the LCR food web research led by Muehlbauer in the FY15-17 Triennial Workplan, and these new efforts will build upon preliminary data collected by GCMRC and NPS in these tributaries. Additionally, this research will help identify the suitability of invertebrate populations in Grand Canyon tributaries to colonize the mainstem river if macroinvertebrate flows are tested, which was identified as a high priority research need in the Food Base Knowledge Assessment.

With respect to brown trout, we will continue ongoing research into the food web effects of trout removal from Bright Angel Creek, which we initiated within the past year, and which will be compared with a similar, pre-removal study led by NPS and collaborators. We will also conduct new research into brown trout feeding habits in Glen Canyon to understand whether brown trout population increases in this reach are related to observed shifts in the invertebrate prey base (i.e., aquatic insects are scarce and New Zealand mudsnails are abundant). This research will be similar to the bioenergetics and prey selection research on rainbow trout that was led by Mike Dodrill as part of the FY15-17 Triennnial Workplan.

Finally, we will initiate new benthic monitoring to track the expansion of quagga mussel into Glen, Marble, and Grand Canyon. Quagga mussels began appearing in Lees Ferry in 2013, and their downstream progression is only being tracked by sparse, ad-hoc efforts. We will develop a scientifically-robust monitoring program for quagga mussels that will include benthic sampling in potential quagga habitats. This effort will describe the extent and magnitude of the quagga mussel invasion downstream of GCD, which will serve as baseline data for change detection in the populations of this species.

Commented [DPB43]: Is there a possible feedback loop here via fish and quagga feeding impacts?

Commented [DPB44]: Don't they feed on non-drifting invertebrates, too – macro-invertebrates on benthic substrates?

Commented [DPB45]: Sampled how? Presumably can't do this from bugs in fish stomach contents, although stomach data would help characterize the relative contributions of different prey taxa so you can weight the results of analyses of invertebrates collected live themselves. Or are feeding behaviors so opportunistic that "relative contributions" just depend on availability?

Commented [DPB46]: I noted for Project E that you may need data on storage of P in biomass, too, to interpret the water chem data on SRP. If P uptake is indeed intense, the greatest fraction may end up in aquatic faunal biomass, with the SRP representing only a kind of "tip of the iceberg." The effects of variation in SRP inputs presumably cascade through the aquatic ecosystem. Should the lab analyses of invertebrate and fish tissue therefore also measure N and P (and are these constant fractions of biomass, or can they vary with organism condition)?

Commented [DPB47]: Just drift sampling, or benthos and macrophyte sampling, too? And would there be any value in Chlorophyll-a monitoring of the water column? Of course, C-a levels are likely quite low, so would there be challenges with detection limits and accuracy?

3. Monitoring in anticipation of novel flow experimentation

The LTEMP includes multiple novel flow experiments (macroinvertebrate production flows, HFEs, and trout management flows) that have the potential to drive large changes in the abundance and composition of the invertebrate prey base. As such, we will conduct regular monitoring of invertebrate drift and benthic sampling at new sites throughout Glen, Marble, and Grand Canyons that will be critical to describing food base response to these flow experiments. Most of these new monitoring sites will be adjacent to tributaries, and at the nodes and anti-nodes of midge abundance identified by Kennedy et al. in their 2016 *BioScience* paper (e.g., Lees Ferry, Nankoweep, Bright Angel, Tapeats, etc.). We will also continue to support the PhD research of Arizona State University graduate student Christina Lupoli describing linkages between emergent aquatic insects and terrestrial species such as birds, bats, and lizards that depend on emergent aquatic insects as prey. We anticipate collaborating with tribal monitoring trips and other citizen scientists, to acquire some of the data needed for this project, including bat and bird acoustic monitoring data. This research will identify the extent to which aquatic invertebrate resource availability affects the broader Grand Canyon ecosystem, and whether changes in aquatic insect abundance owing to "macroinvertebrate production flows" cascade out of the River itself.

To better understand the relationship between the quality of benthic substrates and benthic invertebrates, we will also conduct new research, predominantly in Glen Canyon, on smaller-scale habitat effects on the food base. We will advance learning of habitat-invertebrate relations by: 1) tracking invertebrate response to mechanical scrubbing of rocks and loosening cobbles, which mimic flow-related sediment scouring of benthic substrates, 2) exploring the lateral variation in invertebrate drift along channel cross sections and across flow conditions, 3) linking invertebrate drift patterns to flow and fish spatial abundance patterns using natal origins data and Scott Wright's 2D flow model of Glen Canyon, 4) exploring macrophyte spatial densities in the Lees Ferry reach, and 5) synthesizing what is known about potential declines in *Gammarus* populations from the 1980s to present. Additionally, we will continue field experiments on insect egg laying that were initiated in FY 2017. All of these topics were identified as research needs in the Food Base Knowledge Assessment.

Finally, we will collaborate with Oregon State University graduate student Erin Abernethy to explore aquatic invertebrate genetics in tributaries throughout the Colorado River ecosystem downstream of GCD, a project that is funded by the USGS-NSF joint Graduate Research Improvement (GRIP) Program. This research will identify whether insect populations among tributaries are genetically similar (indicating ongoing genetic exchange), whether these populations have become genetically isolated in the recent past (possibly owing to dam construction and the mainstem becoming inhospitable for aquatic insects), or whether populations are distantly related (indicating genetic exchange among tributaries never occurred, even prior to dam construction). This research might also pair well with work proposed by Larry Stevens at the confluence of Tapeats Creek on the "Hofknecht transition," whereby a diverse suite of aquatic invertebrates present in the creek does not colonize the apparently similar main stem; in support of Stevens' and Abernethy's work we could carry out focused drift studies adjacent to Tapeats Creek to better characterize the spatial dynamics of this pattern.

Commented [DPB48]: And, eventually, Low Summer Flows, in second decade of LTEMP.

Commented [DPB49]: I assume you need data on prey selectivity patterns to make sense of the drift and benthos bug data, or are the fishes, cumulatively across all species and all age classes, essentially opportunistic?

Commented [DPB50]: Spatial nodes, not temporal, right?

Commented [DPB51]: Glad to see this – another part of alignment with EIS/ROD objectives for Natural Processes and probably other resources (recreation, tribal values), too.

Commented [DPB52]: Should you also consider the possibility of biotic flows in the opposite direction, such as allochthonous contributions to aquatic system, per Project E.

Commented [DPB53]: Interesting. How would dam construction and operations affect genetics for insects with high aerial mobility as adults?

4. *Research to enhance learning from novel flow experiments*

Commented [DPB54]: Glad to see these components, which align well with EIS/ROD and long-term AMP objectives, and glad to see it made clear to the stakeholders that non-AMP funding is key to these. I think it is important to have information on how larger scientific work benefits the AMP, even when not AMP-funded.

It is inherently difficult to make predictions about responses in one ecosystem without having contrasting, or control ecosystems, for comparison. As such, we are seeking funding to carry out field research on other tailwaters in the Lower Colorado River Basin, and to conduct syntheses on aquatic food base conditions in tailwaters across the world. On the first point, WAPA-funded research at Davis and Parker Dams in FY2015 identified that there were robust populations of mayflies and caddisflies in these tailwaters in spite of very high levels of load-following (i.e., 10 feet of daily stage change), seemingly contradicting the mechanisms for hydropeaking-induced egg mortality on EPT (e.g., ephemeroptera, plecoptera, and trichoptera) species outlined by Kennedy et al. in their 2016 *BioScience* paper. Studying the abundance and habitat associations of mayflies and caddisflies across all their life stages (i.e., egg, larvae, pupae, adult) in these highly managed tailwaters would identify why these species are able to persist and thrive in spite of extreme load-following flows. By describing how these species are able to persist in these other tailwaters, we will be able to more accurately explain and predict how the aquatic food base downstream of GCD might respond to novel experimental flows, and also which insect taxa are likely to recolonize from Grand Canyon tributaries, or which taxa might be ideal candidates for repatriation. We are seeking funding from the MSCP and Bureau of Reclamation for these studies.

We have also proposed a USGS Powell Center working group that, if funded by USGS, would entail a synthesis of aquatic invertebrate community responses to dam operations throughout the world. Importantly, this synthesis would describe how dam management affects the aquatic food base downstream in a mechanistic fashion. If successful, the Powell Center would fund Muehlbauer's salary for FY 2018. This proposal represents a collaboration between GCMRC scientists (Muehlbauer and Kennedy), the Department of Energy Oak Ridge National Laboratory (Ryan McManamay), the USGS NAWQA water quality program (Daren Carlisle), and several other working group participants from federal and state agencies, universities, and NGOs, with GCMRC scientists as the lead PIs.

3. Budget

FY 2018	
Project	Food Base
Salaries	$689,583
Traveling and Training	$21,800
Operating Expenses	$39,100
Logistics	$32,300
Cooperators (non-USGS)	$52,500
USGS Cooperators	$14,500
USGS Burden	$205,099
Total	$1,054,882
FY 2018 Project Gross Totals: $ 1,054,882	

FY 2019	
Project	Food Base
Salaries	$757,918
Traveling and Training	$22,454
Operating Expenses	$40,273
Logistics	$33,269
Cooperators (non-USGS)	$54,075
USGS Cooperators	$14,935
USGS Burden	$223,640
Total	$1,146,564
FY 2019 Project Gross Totals: $1,146,564	

FY 2020	
Project	Food Base
Salaries	$780,218
Traveling and Training	$23,128
Operating Expenses	$41,481
Logistics	$34,267
Cooperators (non-USGS)	$55,697
USGS Cooperators	$15,383
USGS Burden	$230,235
Total	$1,180,409
FY 2020 Project Gross Totals: $1,180,409	

Project G. Humpback chub population dynamics throughout the Colorado River

1. Investigators

Charles B. Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
David Ward, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Kirk Young, Fish Biologist, US Fish and Wildlife Service
Michael Yard, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Maria Dzul, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Michael Dodrill, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

2. Project Summary

Activities associated with humpback chub are diverse and primarily motivated by the LTEMP EIS and associated Biological Opinion (BiOp). Given the complexity of work done on humpback chub, we group these activities into three main groups: 1) ongoing long-term studies (e.g., monitoring, population models), 2) new or substantially altered research, and 3) translocations and associated research, which we discuss in more detail below.

Ongoing long-term studies.

1. Population modelling that integrates data from mark-recapture efforts in the Little Colorado River (LCR) and Colorado River (CR) will continue to be used to estimate abundances and vital rates (survival, growth and movement) of various size classes of humpback chub in different locations to directly inform triggers, provide context to observed trends, and improve our understanding of humpback chub population ecology. Specific priorities for this workplan include: i) integrating new forms of portable remote antennae data (including shore-based single antennae) that have only recently been incorporated into LCR and CR monitoring of humpback chub, ii) incorporating fish translocated above chute falls into population models to assess translocation effectiveness, iii) analysis of drivers of key population processes, especially humpback chub recruitment and outmigration rates, and iv) analysis of the relative impacts of environmental and individual conditions on adult survival and spawning probabilities with implications for abundance estimates.
2. Monitoring in the LCR in the spring and fall using two trips in each season will continue and use joint agency and tribal staffing. We also plan to explore whether use of additional gear types during fall trips could allow us to estimate fall juvenile abundances

Commented [DPB55]: Please note that HBC monitoring and research was one of the subjects of the Fisheries PEP in FY16, and the present proposal incorporates the findings and recommendations from that PEP.

Commented [DPB56]: Needs to be changed to "throughout the CRE" to avoid any impression that you will be working outside the geography of the AMP.

Commented [DPB57]: The 2017 Knowledge Assessment responses from the Humpback Chub team indicated several areas of uncertainty about status and trends and external drivers. It would be useful if the project summary indicated how the proposed work will help redress these unknowns and uncertainties, anywhere where it has not already done so (thanks for that).

Commented [DPB58]: Specifically the CR between Powell and Mead – important to not leave readers unsure of geographic scope.

in a single, fall trip timed to avoid floods, potentially leading to similar quality data at lower costs and with a smaller footprint in the LCR.

3. We will continue monitoring of humpback chub in the Colorado River near its confluence with the LCR as part of the juvenile chub monitoring (JCM) project. This project will involve a single pre-monsoon season trip to the LCR to estimate juvenile recruitment and outmigration rates, as well as three trips (decreased from four trips in prior years) to a fixed site in the Colorado River just downstream of the LCR confluence to estimate juvenile growth and survival in the mainstem. These sampling efforts also inform estimates of abundances (including adult abundance) and vital rates of various size classes of humpback chub. We plan to slightly decrease the number of nights per CR trip, but also increase the spatial extent of JCM study reach with the goal of increasing the number of marks released and improving population estimates, while also minimizing negative impacts on the wilderness experience in GCNP. We also will incorporate portable remote passive integrated transponder (PIT) antennae into our sampling design.

4. In the short term, we will continue to maintain and operate the remote PIT-tag antenna array in the LCR, however this system is slowly degrading and is unlikely to remain functioning through 2020. Therefore, we are currently testing the effectiveness of a series of shore-based single antennas placed in locations that naturally funnel fish in the lower portion of LCR as a potential replacement. USGS and USFWS have already begun working on this replacement plan and we are optimistic that shore-based antennae can provide as good or better data at a lower costs and with a smaller footprint in the LCR.

New or substantially altered research.

5. Since 2009, mark-recapture studies around the LCR (i.e., the Near Shore Ecology study from 2009 to 2011 and the JCM study from 2012 onwards) have led to a much improved understanding of the drivers of humpback chub population dynamics in the LCR aggregation, including providing data to estimate the relative importance of physical (temperature, turbidity) and biological (rainbow trout, foodbase, density dependence) factors. In recent years, catch in more western aggregations have increased dramatically, however, current sampling is insufficient to determine drivers. Furthermore, the BiOp states a need to determine the drivers of aggregations. For these reasons we propose to establish a fixed site in the western Grand Canyon in which to establish JCM-type sampling (JCM-West) to determine if we can estimate vital rates and abundances (as opposed to catch statistics) with an eventual goal of determining drivers of population dynamics. JCM-West would occur as part of the same trips used for JCM because of the overlap in gear, and personnel and in order to minimize costs (the Rainbow Trout Natal Origins study and JCM were combined logistically in previous workplans). In 2017, we are planning a pilot study to determine the best location for JCM-West with three potential sites currently being considered (Havasu: - RM 158-167, Parashant: 198-205, and Pumpkin Spring: 210-217).

6. We propose augmenting the existing aggregation sampling and to include tribal staff on trips. First, an annual trip will focus on hoop-net monitoring the known aggregations (e.g., 30-36 Mile, LCR, Bright Angel, Shinumo (if not monitored by NPS), Stephens Aisle/Middle Granite Gorge, Havasu, Pumpkin Spring). The primary objective of this annual trip will be to continue a long term CPUE index that has been constructed

since the early 1990s (Persons et al. 2017). A second annual trip will focus more on status and trends of humpback chub in the western Grand Canyon (from Havasu downriver) using a stratified random sampling design. The primary objective of this trip will be to build a long term CPUE index and provide additional information, such as size distributions, which may offer insights into mainstem chub recruitment. A third non-motorized seining trip will provide information on recruitment dynamics across a large spatial extent of Grand Canyon, complementing proposed sampling and extending long-term monitoring of early life-history stage fish. The objective of this trip will be to sample all backwaters throughout Grand Canyon for relative abundance of juvenile humpback chub and other native species.

7. Recent sampling efforts, particularly at western aggregations downstream of Havasu Creek (RM 165), have documented increased catch of early life stage humpback chub in the mainstem Colorado. The natal origin of these small fish is unknown, with potential spawning and rearing occurring in tributaries (i.e., Havasu Creek) or within the mainstem Colorado in western Grand Canyon. Otolith microchemistry approaches have been successfully applied to document movement between mainstem and tributary habitats and provide a tool for identifying sources of humpback chub recruitment. To identify tributary versus mainstem origins of early life stage humpback chub, we propose to use otolith microchemistry on any incidental mortalities, including (if possible) humpback chub juveniles recovered from non-native predators, from projects sampling in Western Grand Canyon (i.e., mainstem monitoring, JCM-West).

Commented [DPB59]: Might the channel mapping in WGC help identify the meso-habitat settings (and relevant characteristics) of the aggregations? If so, it would be useful to mention such cross-linkage between Projects B and G and their alignment with EIS/ROD and AMP objectives.

8. We propose to use drift nets to monitor exit patterns of early larval humpback chub from the LCR and Havasu Creek. Little is known about the timing and magnitude of larval fish outmigration from these tributaries and the overall contribution these larval fish may have on aggregations of humpback chub in the mainstem.

9. Handheld forward looking infrared radar (FLIR) cameras will be used to thermally image the Colorado River and identify warm springs within the mainstem that may be correlated with increased humpback chub catch rates. Thermal imaging cameras have been used to map groundwater inputs and temperature distributions in other Arizona streams and have been shown to be effective at identifying and mapping the extent of warm-water springs at river mile 30 within Grand Canyon. This relatively low-cost tool will allow identification of currently unknown warm water inputs within the Colorado River that may provide important thermal refuges for humpback chub.

10. We propose using humpback chub data collected from 2000 through the present along with existing high resolution habitat data from the LCR to better understand environmental characteristics associated with spawning of humpback chub. By linking incidence of ripe female humpback chub captures to specific locations and environmental variables within the Little Colorado River, we hope to gain a better understanding of where humpback chub spawn. This work will establish methodologies for linking environmental variables to existing long-term fish data so that the existing database is more useable for humpback chub conservation and management.

Translocations and associated research.

11. Coordinate with the Havasupai Nation and the National Park Service to investigate the feasibility of translocating humpback chub to areas above Beaver Falls in

Havasu Creek. If the Havasupai Nation is supportive, we will work with the tribe to implement surveys to monitor translocated fish.

12. We propose to continue translocation of juvenile humpback chub to above Chute Falls on an annual basis and to continue annual monitoring (LTEMP BiOp Conservation Measure). In addition, we propose to assess the efficacy of translocation of juvenile humpback chub into additional predator free areas within the LCR. A number of pools have been identified including those at the mouth of Big Canyon and several within channel pools 3-5 kilometers upstream of Blue Springs which may serve as head-start rearing areas. This research will provide a conservation benefit as a proof of concept for implementation of Tier 1 management actions if and when they are needed.

13. We propose to investigate imprinting in humpback chub to improve translocation methods. If humpback chub imprint on chemical cues of their natal stream as larvae then translocated fish using current methods may not remain in downstream tributaries or mainstem aggregations once they reach reproductive maturity. Many of these fish may instead attempt to return to the LCR to spawn, thereby reducing the likelihood of establishing additional spawning populations to meet downlisting/delisting criteria. We will verify that imprinting occurs in the laboratory using captive reared humpback chub larvae by measuring thyroid hormones known to be linked to olfactory imprinting. This information will then be used to evaluate new methods for conducting translocations, such as stocking ripe adult fish whose offspring will imprint on the new location rather than translocating juvenile fish that have already imprinted on the LCR.

Commented [DPB60]: What factors affect feasibility, and, if any relate to field conditions, does this sub-project require field survey work to confirm or refine information on these conditions?

Commented [DPB61]: What controls are in place vis sources, health, genetic diversity, and parasite loads in the transported cohorts? What other factors might affect success/failure of translocations, including external drivers, and are monitoring systems in place to track these other factors? Learning from the translocation experiments presumably would require such additional information, to help increase understanding of the circumstances in which such translocations may succeed or fail. The LTEMP and its ROD emphasize needs for critical learning, and this is one of the recognized "experiments" from which the AMP must learn, for purposes of adaptive management. Given this, would it be useful for the "proof of concept" trials to include figuring out what needs to be monitored or controlled to ensure that effective learning takes place?

3. Budget

FY 2018	
Project	Humpback Chub
Salaries	$543,952
Traveling and Training	$12,000
Operating Expenses	$139,050
Logistics	$401,477
Cooperators (non-USGS)	$505,000
USGS Cooperators	$47,549
USGS Burden	$300,235
Total	$1,949,263
FY 2018 Project Gross Totals: $1,949,263	

FY 2019	
Project	Humpback Chub
Salaries	$557,778
Traveling and Training	$10,000
Operating Expenses	$103,700
Logistics	$417,716
Cooperators (non-USGS)	$521,000
USGS Cooperators	$31,208
USGS Burden	$298,820
Total	$1,940,222
FY 2019 Project Gross Totals: $1,940,222	

FY 2020	
Project	Humpback Chub
Salaries	$572,286
Traveling and Training	$14,500
Operating Expenses	$108,700
Logistics	$432,613
Cooperators (non-USGS)	$605,000
USGS Cooperators	$15,149
USGS Burden	$311,457
Total	$2,059,705
FY 2020 Project Gross Totals: $2,059,705	

Project H. Salmonid Research Project

1. Investigators

Josh Korman, Fish Biologist, EcoMetric, Inc.
Michael Yard, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
David Rogowski, Fish Biologist, Arizona Game and Fish Department
Clay Nelson, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Ken Sheehan, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Charles Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Michael Dodrill, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Kim Dibble, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

2. Project Summary

Nonnative salmonids, such as rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta*, are considered priority-species in the GCDAMP because of their recreational value and potential negative effects on humpback chub (*Gila cypha*) an endangered species (Yard et al., 2011, Yackulic unpublished data). Although rainbow trout are the more desired of the two sport fish, brown trout are likely establishing a spawning population in Glen Canyon, and their occurrence further complicates the co-management of the tailwater fishery and downstream reaches of the Colorado River. Currently, the number of policy levers available to enhance chub populations is limited to actions that are focused on regulating trout movement and abundance through use of flows or mechanical removal (Coggins et al. 2011). Not surprisingly then, trout were a very important component of the LTEMP EIS and a major consideration in the flow decisions identified in the selected alternative. The overarching purpose of this project is to determine the effects of flows identified in the Record of Decision (ROD) on the recruitment of young-of-year trout in Glen Canyon, the growth rate of juveniles and adults, and dispersal of young-of-year trout from Glen Canyon. This research project proposes to evaluate (1) the effect of trout management flows (TMFs) on recruitment and dispersal; (2) the effects of higher and potentially more stable flows in spring and summer during equalization events on recruitment, growth, and dispersal; (3) the effect of fall HFEs on recruitment of trout in Glen Canyon, either through direct effects on juvenile survival or through reduced egg deposition in later years driven by reduced growth of trout (which reduces fecundity and rates of sexual maturation); (4) the effect of spring HFEs on recruitment, growth, and dispersal; and (5) develop a rainbow trout recruitment/outmigration model. Summarized below are monitoring and research elements that address the primary study objectives:

Commented [DPB62]: Please note that salmonid monitoring and research was one of the subjects of the Fisheries PEP in FY16, and the present proposal incorporates the findings and recommendations from that PEP.

Commented [DPB63]: Would it help with coordination to have someone from AZGFD on the team, as is the case with Project I (Aquatic Invasive Species)?

Commented [DPB64]: As well as in the LTEMP EIS and ROD

Commented [DPB65]: And potentially on Other Native Fishes and on Natural Processes such as food web dynamics.

Commented [DPB66]: The 2017 Knowledge Assessment responses from the Rainbow Trout and Invasive Species teams indicated several areas of uncertainty about RBT and BRT status and trends and external drivers, as well as the need to monitor the effects of the LTEMP flow experiments and other actions on the salmonids. It would be useful if the project summary indicated how the proposed work will help redress these unknowns and uncertainties.

Ongoing Monitoring Studies

- ***1. System Wide Electrofishing –*** This project element provides long-term monitoring data on the longitudinal distribution and status of the fish community in the Colorado River ecosystem (CRe) from Lees Ferry to Lake Mead. The project uses electrofishing and hoop-netting CPUE indices to track relative status and trends of the most common native and nonnative fish species in the CRe. The current monitoring program is designed to be able to detect population level changes in target species over a five-year time scale.
- ***2. Rainbow Trout Monitoring in Glen Canyon –*** The objective of this project element is to monitor the basic fish population characteristics, including relative abundance, size composition, distribution, and recruitment of rainbow trout and brown trout. The current monitoring program is designed to be able to detect population level changes over a five-year time scale.
- ***3. Lees Ferry Creel Survey & AGFD Citizen Science Project –*** This project element evaluates the quality and changes in the recreational experience of angling in the rainbow trout fishery in Lees Ferry, Glen Canyon National Recreation Area (Rogers 2015). Currently, estimates of angler catch quality (i.e., number of fish ≥ 14" and fish ≥ 20") cannot be reliably determined from these surveys without substantive bias; therefore, AGFD proposes to conduct a citizen science project that utilizes fishing guides to collect length data on fish caught by their clients.

New Research Studies

- ***4. Experimental Flow Assessment for Rainbow Trout –*** There are two main elements to this study, we propose to implement a *multi-reach mark-recapture sampling design* that focuses on marking trout by using a combination of VIE-tags (≤75 mm) and PIT-tags (≥75 mm) in three 2-km reaches (located near -3.5 RM, -9RM, and -12.5 RM). These data will be integrated into an open population model to estimate abundance, recruitment, and growth in each reach. TMFs are a key element of the LTEMP EIS and are intended to reduce recruitment of rainbow trout in Glen Canyon to avoid boom-and-bust cycles but more importantly, to limit downstream dispersal. Comparing the trends in trout populations between summer months in years when TMFs are conducted, and between fall months or spring months in years when fall- or spring-HFEs are conducted provides a rigorous evaluation of TMF and HFE effects (that will be replicated in three reaches). By having PIT-tag estimates of recruitment in the same location where *Rainbow Trout Early Life Stage Survival (RTELSS)* estimates of abundance are obtained, allows for both sets of results to be integrated into the same open population model (Korman and Yard 2017). Logistically, the *multi-reach mark-recapture sampling design* would be similar to the Natal Origins effort in Glen Canyon, but is restricted to three reaches to reduce trip length and cost. Modelling and other analytical approaches for this element have already been developed which reduces analytical costs (Korman and Yard, *in review*). We propose to move all *RTELSS* sampling into the three study reaches (currently sites are distributed throughout Glen Canyon). In each reach, sites will be continuously distributed on the left and right bank and cover a total of 1 km of shoreline on each side.

These 1-km sections will be selected so that a low-angle shoreline is present on one side and a high-angle shoreline on the other. This design offers a number of advantages: a) the continuous sites allow us to conduct more effective mark-recapture of small fish using VIE-tags. *RTELSS* currently assumes that capture probabilities are constant across all trips and this has led to problems in the past that this approach will avoid (Avery et al. 2015); b) we expect TMFs to be more effective in low angle shorelines than steep ones because small fish are more likely to be stranded in the former shoreline type. Comparing the trends in populations between May and August in years when TMFs are conducted provides a rigorous evaluation of TMF effects (which will be replicated in three reaches); and c) by having PIT-tag estimates of recruitment in the same location where *RTELSS* VIE-tag estimates of abundance are obtained, we will be able to integrate both sets of results in the same open population model. That is, data from both efforts will be used to provide more robust and consistent estimates of how flow is effecting survival and recruitment of young-of-year as well as other size-classes of trout.

- ***5. Rainbow Trout Recruitment and Outmigration Model –*** The ability to predict the strength of rainbow trout recruitment and outmigration relative to management alternatives outlined in the LTEMP is of central importance to effective management of multiple resources in the CRe. The model is designed to integrate data from different research and monitoring schemes and will be used in testing various hypotheses of drivers (e.g., nutrients, flow, rainbow trout densities, etc.) and predicting rainbow trout responses to alternative flows and physical conditions. Also the model will be used to determine the statistical power of different monitoring schemes to detect effects of different flow experiments.
- ***6. Young-Of-Year Brown Trout Otolith Study –*** Brown trout populations have increased recently in Glen Canyon and pose a threat to the rainbow trout fishery and chub near the LCR. Disturbance from TMFs and HFEs, particularly during spring timed flows when brown trout are just emerging from gravel may adversely affect their survival. Secondly, TMFs and HFEs may also affect growth following post emergence, and by extension influence their ultimate survival and recruitment. Otolith growth studies by Korman and Campana (2008) have shown that rainbow trout growth is negatively influenced by changes in discharge and rate. Because this is an informative tool, we propose using otoliths for measuring daily growth rates in young-of-year brown trout to determine if flow magnitude, duration, and timing influence growth. Also by back-calculating hatch and emergence dates, we will identify critical developmental periods when flow manipulation and/or other potential management actions may be effectively targeted at vulnerable brown trout life stages.

3. Budget

FY 2018	
Project	
Salaries	$268,698
Traveling and Training	$49,260
Operating Expenses	$52,900
Logistics	$269,422
Cooperators (non-USGS)	$453,669
USGS Cooperators	$0
USGS Burden	$180,083
Total	$1,274,032

FY 2018 Project Gross Totals: 1,274,032

FY 2019	
Project	
Salaries	$324,782
Traveling and Training	$49,260
Operating Expenses	$55,400
Logistics	$285,559
Cooperators (non-USGS)	$463,313
USGS Cooperators	$0
USGS Burden	$199,800
Total	$1,378,114

FY 2019 Project Gross Totals: 1,378,114

FY 2020	
Project	
Salaries	$341,265
Traveling and Training	$51,760
Operating Expenses	$52,400
Logistics	$302,479
Cooperators (non-USGS)	$473,246
USGS Cooperators	$0
USGS Burden	$208,652
Total	$1,429,802

FY 2020 Project Gross Totals: 1,429,802

Literature

Avery, L. A., Korman, J., & Persons, W. R. 2015. Effects of increased discharge on spawning and age-0 recruitment of rainbow trout in the Colorado River at Lees Ferry, Arizona. North American Journal of Fisheries Management, 35: 671-680.

Coggins, L.G. Jr., Yard, M.D., and Pine, W.E. III. 2011. Nonnative fish control in the Colorado River in Grand Canyon, Arizona: an effective program or serendipitous timing? Trans. Am. Fish. Soc., 140:456-470.

Korman, J. and Campana, S.E. 2008. Effects of hydropeaking on nearshore habitat use and growth of age-0 rainbow trout in a large regulated river. Trans. Am. Fish. Soc., 138:76-87.

Korman, J., and M.D. Yard. 2017. Effects of environmental covariates and density on the catchability of fish populations and the interpretation of catch per unit effort trends. Fish. Res. 189:18-34.
Korman, J., and M.D. Yard. *In review*. Trends in recruitment, abundance, survival, and growth over a boom-and-bast cycle of a rainbow trout tailwater population. Submitted to Trans. Am. Fish. Soc., Dec. 18, 2016.
Rogers, S. 2015. Fisheries Management Plan Colorado River - Lees Ferry 2015-2025. Page 15. Arizona Game and Fish Department, Phoenix, AZ.
Yard, M.D., Coggins, L.G., Baxter, C.V., Bennett, G.E., and Korman, J. 2011. Trout piscivory in the Colorado River, Grand Canyon: effects of turbidity, temperature, and fish prey availability. Trans. Am. Fish. Soc., 140:471-486.

Project I. Aquatic Invasive Species

1. Investigators

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Kenneth Sheehan, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
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Ken Hyde, Chief of Science and Resource Management, National Park Service, Glen Canyon National Recreation Area & Rainbow Bridge National Monument
Kirk Young, Fish Biologist, U.S. Fish and Wildlife Service
Mike Yard, Fish Biologist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Charles Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

2. Project Summary

Declines in native fish populations throughout the southwest are commonly linked to adverse interactions with Aquatic Invasive Species (AIS). The regulation and control of invasive fish is an important management action identified in the 2002 humpback chub recovery goals (under revision) as well as in the LTEMP EIS and its associated Biological Opinion. In this work plan we propose a develop a comprehensive strategy in collaboration with the National Park Service, the US Fish and Wildlife Service, the Arizona Game and Fish Department, and Tribal agencies to reduce the presence and expansion of AIS in three primary ways:

1. By refining existing monitoring efforts and using new tools to **improve early detection of AIS**.
2. By **assessing the risk of warm-water nonnative fish** to humpback chub and other native fishes through new research in the Little Colorado River and Colorado River Ecosystem and synthesis of existing data/literature.
3. By developing **an action plan that includes the evaluation of existing management strategies** and new tools to manage AIS.

Preventing new invasions is the least expensive and most effective way to control nonnative species when compared to the cost of control projects after invasions occur (Leung and others, 2002). Therefore, the first component of our comprehensive strategy is to **improve detection** of potentially problematic AIS in the Little Colorado River (LCR) and in the Colorado River Ecosystem (CRe) in Grand Canyon by expanding monitoring efforts and testing new detection tools. Long-term monitoring to detect

Commented [DPB67]: Please note that AIS monitoring and research was one of the subjects of the Fisheries PEP in FY16, and the present proposal incorporates the findings and recommendations from that PEP.

Commented [DPB68]: … and ROD

Commented [DPB69]: It is also important to mention that the project will directly address monitoring needs highlighted in the EIS and ROD, and in the 2017 Knowledge Assessment. The EIS/ROD lays out specific objectives for invasive aquatic species management, mandates assessing how mechanical removal affects AIS, and emphasizes the need to monitor how all other experimental and management actions may affect AIS.

Commented [DPB70]: Please include Literature Cited section.

Commented [DPB71]: Would the selection of detection and management tools depend on where the 'gateways' are for incoming AIS? For example, to what extent are we dealing with existing AIS populations in situ, versus new individuals arriving from elsewhere? And if from elsewhere, from where? Clearly you view the LCR watershed as a potential large source, and the 2017 Knowledge Assessment and other discussions have identified concerns about what makes it through the GCD, too. Lake Mead presumably also is a large source. What else? Is there any effort to inform/discourage anglers about "bait fish"?

nonnative fishes is currently conducted by the Arizona Game and Fish Department (AGFD) in Lees Ferry and throughout the CRe. We propose to increase these monitoring efforts in Lees Ferry by adding three additional one-night sampling trips and expanding spatial coverage to evaluate four additional sites where warm-water species are likely to aggregate and spawn in order to maximize our ability to detect AIS range expansions and unwanted species passing through the dam. Monthly monitoring during the summer months between the dam and Lees Ferry will focus on locations with warmer water where nonnative fishes are most likely to occur. Currently, the AGFD conducts system-wide electrofishing and hoop netting surveys from Lees Ferry (RM 0) to Pearce Ferry (RM 281). This project and other fish monitoring efforts such as the humpback chub aggregation monitoring and the juvenile chub monitoring project also provide important detection data related to AIS and we propose these activities continue (see Projects G and H). As the elevation of Lake Mead has decreased due to drought, the western segment of the river has reemerged, creating the need to extend sampling efforts an additional 15 miles to the Lake Mead interface. Additional surveillance by the US Fish and Wildlife Service and the Grand Canyon Monitoring and Research Center (GCMRC) will be conducted upstream of Blue Springs in the LCR to identify sources of nonnative fish that are likely to move into the CRe during high flows. New tools such as Environmental DNA (eDNA) will be tested to validate the presence or absence of key invasive species and determine the spatial extent of invasions in the LCR and CRe. Environmental DNA can have higher sensitivity and lower cost than traditional sampling methods especially when attempting to detect very rare organisms. Water samples for eDNA analysis are relatively easy to collect in conjunction with exiting monitoring trips and may also lend themselves to cost effective collection using citizen science volunteers, although research and additional development to determine effectiveness of these tools will be needed. In addition, methods to assess the infestation of Asian tapeworm in humpback chub will continue in the LCR and additional monitoring will be extended to humpback chub populations in the CRe. Collectively, the expansion of existing monitoring efforts combined with new detection tools are a critical first step for preventing the establishment and spread of AIS in Grand Canyon.

Assessing the risks posed by existing or new AIS is the second component of our comprehensive strategy. Hilwig and Andersen (2010) compiled a literature review of the potential risks posed by individual species, but those risks need to be updated based on expected future conditions in the LCR and CRe in a changing climate. Although extensive research to evaluate rainbow and brown trout predation on juvenile humpback chub under various environmental conditions has been conducted, other warm-water invasive species in the LCR may be just as detrimental to humpback chub and other native fish populations. To that end, risks posed by warm-water invasive fishes such as channel catfish and bullhead catfish will be quantified using diet analysis and bioenergetics modeling. Laboratory studies will be conducted to quantify predation risk from common carp and small bodied fishes such as fathead minnow and plains killifish on humpback chub eggs and larvae. These studies will determine if warm-water invasive fishes present more or less of a predation threat to juvenile chub than predation by trout. This information gives context from which to evaluate potential management actions such as trout removal and will ensure that any future AIS removal efforts are focused only on species that pose the highest threat to chub populations.

Commented [DPB72]: For consistency, "AIS"?

Commented [DPB73]: Is there a need to calibrate the eDNA findings, and if so, wouldn't that require synchronizing sampling for eDNA with the direct-capture. Also, it might be useful to have a clearer statement (or report) on the limitations of electrofishing and hoop netting to survey for AIS, e.g., inability to capture organisms in some micro- and meso-habitats (including deep benthic?). Such information would give the AMP a better sense of the limits on detection using different methods, for comparative cost/risk/benefit assessments.

Commented [DPB74]: Please include Literature Cited section.

Commented [DPB75]: Wouldn't one also need to look at predator and prey behaviors (foraging and avoidance behaviors, differences in where and when different species may occur in different habitat settings or how they behave under different habitat conditions, etc.) to look for circumstances that might favor or disfavor predation?

Commented [DPB76]: The more/less question is important, but so is the question of the cumulative effects of all predation. The native fish are swimming a "gauntlet" of predators with which they have no evolutionary experience. Helping the native fishes survive this gauntlet in sufficient numbers to maintain or expand their own numbers presumably requires some combination of reducing the density of attackers and increasing the availability of habitat conditions that afford the natives some protection.

Commented [DPB77]: Again, "threat" here means significant contribution to chub mortality, which hinges on the numbers and food consumption rates of the AIS as well as on the extent to which these AIS forage in habitat settings/under habitat conditions where chub will also be present – more than just matters of bioenergetics and gape sizes.

The most challenging aspect of an invasive species management program is that removal of AIS is typically very difficult and management strategies are rarely in place *a priori* to address and respond to new invasions. Therefore, the third element of our comprehensive strategy is to develop an **action plan that incorporates tools to manage AIS** in the LCR and CRe. We propose to evaluate and summarize management actions and tools that have been used successfully and unsuccessfully in other systems to control AIS. For example, rapidly emerging genetic technologies such as YY chromosomal supermales (Herrera and Cruz 2001, Cotton and Wedekind 2007) that gradually eliminate female reproductive fish in a population through swamping with infertile fish shows promise for reducing or eliminating AIS. Potential management strategies will be summarized and combined with information from the risk assessment (above) to determine which new AIS pose the largest threat to native populations, and further, identify what actions management agencies might take to reduce or eliminate those populations if detected through monitoring activities. In addition, we will conduct research to evaluate the efficacy of using liquid ammonia as a new fish management tool in the LCR (Ward et al. 2013). Isolated pools between Grand Falls and Blue Springs will be treated with an experimental dose of liquid ammonia in June prior to monsoon flooding to minimize transport of invasive fishes downstream into the CRe during high flows. Locations will be identified and treated in coordination with the Navajo Nation and the AGFD and results of these small-scale experimental treatments will be evaluated for potential use in other tributaries. By being proactive in developing a comprehensive action plan and by evaluating new technologies and methods to control AIS, GCMRC will take a leading role in science efforts to control or eliminate nonnative aquatic nuisance species in the LCR and in the broader CRe.

Commented [DPB78]: I am not sure what is meant by this term here. Do you mean "already in place and pre-aligned to address new AIS?"

Commented [DPB79]: The LTEMP EIS/ROD only provide for mechanical removal as a management action. This part of Project I goes beyond that, to evaluate alternative methods for controlling AIS. This idea is fully consistent with the objectives of the AMP overall. But the GCMRC is not responsible for making the key decisions that trigger actions against AIS. The GCMRC role here should not be to develop the action plan per se, but to identify and evaluate options that are alternatives to mechanical removal or alternative ways to carry out mechanical removal (e.g., via liquid ammonia), with the results being presented as advice to the resources managing agencies and AMP stakeholders. Some of these options may also satisfy tribal concerns about treatment of aquatic life forms.

Commented [DPB80]: Need Lit.Cit. section

Commented [DPB81]: Need Lit.Cit. section

3. Budget

FY 2018	
Project	
Salaries	$179,961
Traveling and Training	$7,000
Operating Expenses	$20,304
Logistics	$25,524
Cooperators (non-USGS)	$29,140
USGS Cooperators	$0
USGS Burden	$61,399
Total	$323,328

FY 2019	
Project	
Salaries	$185,359
Traveling and Training	$16,000
Operating Expenses	$18,004
Logistics	$68,768
Cooperators (non-USGS)	$29,652
USGS Cooperators	$0
USGS Burden	$75,804
Total	$393,587

FY 2018 Project Gross Totals: $323,328

FY 2019 Project Gross Totals: $393,587

FY 2020	
Project	
Salaries	$190,921
Traveling and Training	$70,652
Operating Expenses	$17,604
Logistics	$30,528
Cooperators (non-USGS)	$30,168
USGS Cooperators	$0
USGS Burden	$81,428
Total	$421,300

FY 2020 Project Gross Totals: $421,300

Project J. Socioeconomic Monitoring and Research in the Colorado River Ecosystem

1. Investigators

Lucas Bair, Economist, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
David Brookshire, Professor Emeritus, University of New Mexico
Cathy Cullinane Thomas, Economist, U.S. Geological Survey
John Duffield, Research Professor, University of Montana
Todd Gaston, Economist, U.S. Bureau of Reclamation
Tom Gushue, GIS, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
Mathew Reimer, Associate Professor, University of Alaska
Michael Springborn, Assistant Professor, University of California at Davis
Charles Yackulic, Research Statistician, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

2. Project Summary

This project is designed to identify preferences for and economic values of downstream resources and evaluate how these metrics are influenced by Glen Canyon Dam operations, including proposed experiments in the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS). The research will also integrate economic information from the project with data from long-term and ongoing physical and biological monitoring and research studies led by the Grand Canyon Monitoring and Research Center (GCMRC) to develop integrated assessment models that will improve the ability of the Glen Canyon Dam Adaptive Management Program (GCDAMP) to evaluate and prioritize management actions, monitoring and research.

This project involves three related socioeconomic monitoring and research elements. These elements build on socioeconomic research in the GCDAMP Fiscal Years 2015 – 2017 Triennial Budget and Work Plan (FY15-17 TWP) and include: a) interrelated recreation studies that involve the development of a recreational experience simulation model to provide the capability to evaluate recreational resource impacts and tradeoffs under management actions affecting Colorado River flow, development of a regional economic impact model of Glen Canyon angling to understand flows and economic impact in the region, and implementation of a Grand Canyon whitewater guide survey to identify and evaluate key attributes to the whitewater recreational experience (**Element 1**); b) implementation of a tribal member population survey to assess the impact of GCD operations on tribal preference for and value of downstream resources (**Element 2**); and c) continued development and integration of decision support models, using economic metrics, to evaluate management actions and future scenarios, including proposed

Commented [DPB82]: The proposal would benefit from a summary of how this project aligns with the LTEMP EIS/ROD objectives and long-term AMP objectives. The clearest alignments are with two resource topics: Recreational Experience and Tribal Resources, but the decision support tools (Element 3) could be useful for the managers of essentially all resources (see my comments below). Additionally, it would be useful to see a discussion of how this effort aligns with activities in Reclamation's FY18-20 work plan, which also includes actions focused on tribal values and perspectives. Integration will be crucial over the course of implementing the LTEMP. Would it benefit coordination to have one of the tribal liaisons on the Project J team?

experiments in the LTEMP EIS, and prioritize monitoring and research on resources downstream of GCD (**Element 3**).

Element 1: This project element would build on the research accomplished in Project 13.1 in the FY15-17 TWP. This includes utilizing the economic values identified with Grand Canyon whitewater boating and Glen Canyon angling to expand on a scenario analysis model developed for the LTEMP EIS, to estimate the net economic value of whitewater boating and angling under various flow scenarios including experimental flows considered in the LTEMP EIS. This modeling would incorporate up-to-date economic value information estimated for Project 13.1 in the FY15-17 TWP. Simulation models and visualization tools to evaluate experimental flows and other management actions will be developed in a web-based platform and hosted by GCMRC. The project would also develop a regional economic impact model of Glen Canyon angling, utilizing settings from the recreational experience scenario analysis model. The regional economic impact model would allow for an assessment of the regional economic impacts of variation in guided and non-guided angler participation in Glen Canyon. The model would rely on angler expenditure data collected in the angler surveys administered for Project 13.1 in the FY15-17 TWP. The project element would also implement a Grand Canyon whitewater guide (i.e., commercial whitewater guides) survey to identify and evaluate key recreational experience attributes that may differ under alternative flow regimes and events such as HFEs, low steady flows and other experiments in the LTEMP EIS. This survey would allow the GCDAMP to better understand impacts to the whitewater recreational experience, building on the economic surveys in Project 13.1 in the TWP FY15-17.

Commented [DPB83]: It is not clear why it is necessary to continue investing in the model developed for the EIS, when you can now begin collecting data on actual implementation and its impacts. Presumably the model now identifies (and weights?) the economic variables (recreational experience attributes) that need to be monitored, because they potentially vary in response to different flow conditions. Presumably other aspects of system state (e.g., campsite conditions) also affect these responses. Could you systematically collect data on these variables, to build a database of recreational experience state(s) before, during (?), and after flow experiments and other required release events (e.g., for augmentation, supplemental power generation, etc.), which in turn would give you the data you need to assess the actual impacts of the ROD-mandated flow experiments – the data on which are needed for AMP learning and adaptive management?

Element 2: This project element would build on the qualitative research being conducted in Project 13.2 in the FY15-17 TWP. The qualitative research is being undertaken through workshops with tribes involved in the GCDAMP, coordinated with recent work, including a National Park Service non-use study focused on national and regional populations (Duffield et al. 2016), as well as direct use recreation studies (Bair et al. 2016, Duffield et al. 2016). The proposed quantitative population-level tribal research is designed to provide an efficient and timely approach to tribal information needs related to values, perspectives and knowledge of Colorado River Ecosystem resources. The population surveys would expand on the qualitative effort in Project 13.2 in the FY15-17 TWP and use a set of standard methods extensively used in resource economics studies for valuing ecosystem services. The research would provide core information, informing management and associated trade-offs related to operation of GCD.

Commented [DPB84]: What is the current state of FY15-17 Project 13.2? That project was a package, to be completed by the end of FY17. Will that project be completed, what is being learned (FY17 is half over), and in what ways will J.2 expand on this? Additionally, it would help to explain the kinds of "values, perspectives and knowledge" that will be considered. Also, one of the long-term challenges for the AMP has been the lack of specific indicators of the 'state of the system' from the standpoint of tribal values – indicators that could be tracked to provide information on whether and how AMP actions affect the condition of the system from various tribal perspectives. The EIS/ROD states the following goal for "Tribal Resources," to "[m]aintain the diverse values and resources of traditionally associated Tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons." Project J.2 and its predecessor, FY15-17 Project 13.2, could help with articulating the indicated "values and resources." This alignment is crucial. How close will we be to an initial list of tribal "values and resources" amenable to monitoring, by the end of FY17? Also, shouldn't funding be proposed as contingent on the results and evaluation of FY15-17 Project 13.2?

Element 3: This project element would develop a series of integrated assessment models to improve the GCDAMP's capacity to organize scientific information and evaluate and prioritize, monitoring, research and management alternatives specific to the operation of GCD, including proposed flow experiments in the LTEMP EIS. This project element will build on the framework of a bioeconomic model developed to evaluate rainbow trout management strategies in relation to humpback chub population goals (Bair et al. In preparation) and ongoing research in Project 13.3 in the FY15-17 TWP. Ongoing research includes the exploration of which uncertainties in humpback chub population parameters have the greatest implications for management decisions and the explicit trade-offs (efficacy and cost) between trout management flows (TMFs) at GCD and rainbow trout removals at the Little Colorado River (LCR), in an attempt to achieve adult humpback chub population goals. Additional modeling research will systematically assess management triggers related to rainbow trout removal (e.g., adult humpback chub, juvenile humpback chub recruitment, etc.), address the impacts on management decisions of interannual variation and potential long-term trends in both rainbow trout recruitment at GCD and humpback chub recruitment in the LCR, and explore which uncertainties in population parameters and experimental flow responses (e.g., TMFs) have the greatest implications for management decisions. We will also work to use ongoing research and expert elicitation to develop decision tools to inform management of nonnative species and the implementation of macroinvertebrate production flows. In parallel to the integrated assessment modeling, a conceptual model will be developed in coordination with related ongoing economic and systems modeling research by Argonne National Laboratory and the University of Oklahoma's, Center for Energy, Security and Society. The conceptual model will assist in the prioritization of analytical model development and the integration and standardization of analytical models and parameters.

Commented [DPB85]: I found the preceding sentence a bit too abstract, but the one-line summary in the second paragraph above plus this [highlighted] sentence gave me the key I needed, and I have seen presentations by Bair on how these decision support tools help compare the trade-offs entailed in different management decisions – here concerning RBT and HBC. But I am not sure if this should be characterized as "research." It seems to be more an application of a methodology to build decision support tools that the AMP can use to compare the potential pros and cons of different management actions. From a stakeholder standpoint, the tools will be the valuable outcome of Element 3, for a crucial reason: The "Table 4" of the EIS and ROD repeatedly states that all experimental and management actions are to be checked regularly to make sure they do not result in "long-term unacceptable adverse impacts" on the 11 focal resources addressed by the LTEMP. The challenge of such checking of course is that an action that results in "adverse impacts" to one resource may in fact benefit some other resource. As a result, the AMP crucially needs tools to help in evaluating trade-offs. The DSTs you propose are one such type of tool. [I should add: Are there others that might also help? Would it be useful to inform the AMP about a range of options?]

3. Budget

FY 2018	
Project	Socioecon
Salaries	$139,050
Traveling and Training	$10,000
Operating Expenses	$1,000
Logistics	$500
Cooperators (non-USGS)	$174,000
USGS Cooperators	$0
USGS Burden	$44,363
Total	$368,913

FY 2019	
Project	Socioecon
Salaries	$143,100
Traveling and Training	$10,000
Operating Expenses	$1,000
Logistics	$500
Cooperators (non-USGS)	$172,000
USGS Cooperators	$17,000
USGS Burden	$45,356
Total	$388,956

FY 2018 Project Gross Totals: $368,913

FY 2019 Project Gross Totals: $388,956

FY 2020	
Project	Socioecon
Salaries	$147,150
Traveling and Training	$10,000
Operating Expenses	$1,000
Logistics	$500
Cooperators (non-USGS)	$148,000
USGS Cooperators	$48,000
USGS Burden	$45,689
Total	$400,339

FY 2020 Project Gross Totals: $400,339

Project K. Geospatial Science and Technology Project

1. Investigators

Thomas M. Gushue, U.S. Geological Survey
Timothy Andrews, U.S. Geological Survey
James Hensleigh, U.S. Geological Survey

2. Project Summary

The geospatial and information technology industries continue to change and expand at a rapid pace. Much of this growth is driven by advances in technology -- from improved sensors for monitoring the Earth to increased digital data storage capacity to new systems designed for processing Big Data faster and more efficiently to the greater emphasis of the Internet Of Things where the reliance of web-based technologies have revolutionized our world. The purpose of this project is to continue to advance the Grand Canyon Monitoring and Research Center's ability to leverage many of these new technologies for the benefit of the Center, the science projects described within this work plan, and the larger adaptive management program that they serve.

Commented [DPB86]: For the final version, I think it would be appropriate to note that these information systems are crucial for allowing the AMP to review data that can inform time-sensitive decisions on experimental and management actions under the EIS/ROD. This capability is crucial to effective decision-making during implementation of the LTEMP.

The Grand Canyon Monitoring and Research Center continues to collect, store, process, analyze, and serve an ever-growing amassment of digital data. Much of the data that now exists in the Center has a geospatial component to it. The importance of being able to effectively manage these data has never been greater as technological advances have increased both the demand and the expectancy of more open data availability. This project will continue to build and maintain systems that will handle these data needs, as well as provide high-level support to other science projects in the form of data processing, data management and documentation, geospatial analysis, and access to the Center's data holdings.

3. Budget

FY 2018	
Project	
Salaries	$183,719
Traveling and Training	$6,000
Operating Expenses	$20,000
Logistics	
Cooperators (non-USGS)	
USGS Cooperators	
USGS Burden	$54,527
Total	$264,246

FY 2018 Project Gross Totals: $264,246

FY 2019	
Project	
Salaries	$189,231
Traveling and Training	$6,000
Operating Expenses	$20,000
Logistics	
Cooperators (non-USGS)	
USGS Cooperators	
USGS Burden	$55,960
Total	$271,191

FY 2019 Project Gross Totals: $271,191

FY 2020	
Project	
Salaries	$194,908
Traveling and Training	$6,000
Operating Expenses	$20,000
Logistics	
Cooperators (non-USGS)	
USGS Cooperators	
USGS Burden	$57,436
Total	$278,344

FY 2020 Project Gross Totals: $278,344

Project L. Administration

The USGS Administration budget covers salaries for the communications coordinator, the librarian, and the budget analyst for GCMRC. The vehicle section covers GSA vehicle costs including monthly lease fee, mileage costs, and any costs for accidents and damage. DOI vehicles are also included in this section of the budget to pay for vehicle gas, maintenance, and replacements costs. Leadership personnel covers salary for the GCMRC Chief and Deputy Chief, half the salary for one program manager, and some of the travel and training costs for these personnel. AMWG/TWG travel covers the cost of GCMRC personnel to travel to the AMWG and TWG meetings. SBSC Information Technology (IT) overhead covers GCMRCs IT equipment costs. Logistics base costs covers salaries and travel/training. These base costs also include a $35,000 contribution to the equipment and vehicles working capital fund.

Budget

FY 2018	
Project	Admin
Salaries	$867,201
Traveling and Training	$55,000
Operating Expenses	$239,000
Logistics	
Cooperators (non-USGS)	$103,600
USGS Cooperators	
USGS Burden	$305,020
Total	$1,569,821

FY 2018 Project Gross Totals: $ 1,569,821

FY 2019	
Project	Admin
Salaries	$896,578
Traveling and Training	$57,500
Operating Expenses	$245,500
Logistics	
Cooperators (non-USGS)	$106,708
USGS Cooperators	
USGS Burden	$315,092
Total	$1,621,378

FY 2019 Project Gross Totals: $1,621,378

FY 2020	
Project	Admin
Salaries	$926,936
Traveling and Training	$60,000
Operating Expenses	$251,000
Logistics	
Cooperators (non-USGS)	$109,909
USGS Cooperators	
USGS Burden	$325,161
Total	$1,673,006

FY 2020 Project Gross Totals: $1,673,006

Appendix A. Preliminary Budget Estimates

Project	Project Title	FY 2018	FY 2019	FY 2020
A	Streamflow, Water Quality, and Sediment Transport	$1,396,000	$1,424,000	$1,453,000
B	Sandbar and Sediment Storage Monitoring and Research	$1,370,000	$1,416,000	$1,460,000
C	Riparian Vegetation	$749,000	$765,000	$788,000
D	Geomorphic Effects of Vegetation Management and Dam Operations	$531,000	$592,000	$543,000
E	Nutrients and Temperature as Ecosystem Drivers	$689,000	$551,000	$514,000
F	Aquatic Invertebrate Ecology	$1,055,000	$1,147,000	$1,180,000
G	Humpback Chub Monitoring and Research	$1,949,000	$1,940,000	$2,060,000
H	Salmonid Monitoring and Research	$1,274,000	$1,378,000	$1,430,000
I	Invasive Aquatic Species	$323,000	$394,000	$421,000
J	Socio-economics	$369,000	$389,000	$400,000
K	Geospatial Science and Technology	$264,000	$271,000	$278,000
L	Administration	$1,570,000	$1,621,000	$1,673,000
	Proposed Gross Total	**$ 11,539,000**	**$ 11,888,000**	**$ 12,200,000**
	Anticipated AMP Funding Available (Assuming 80.63% of Funding and 1% CPI)	**$8,890,000**	**$8,979,000**	**$9,069,000**
	Long/Short	**($2,649,000)**	**($2,909,000)**	**($3,131,000)**